COURSE		DEVIATION

Deviation scale: 5 4 3 2 1 0 1 2 3 4 5

Course	
N	0°
	15°
	30°
NE	45°
	60°
	75°
E	90°
	105°
	120°
SE	135°
	150°
	165°
S	180°
	195°
	210°
SW	225°
	240°
	255°
W	270°
	285°
	300°
NW	315°
	330°
	345°
	360°

WEST   EAST

AIR NAVIGATION

by

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PREFACE

THE main aim of this book is to meet the needs of the many who, with no previous acquaintance with the subject, wish to acquire a working knowledge of air navigation in a somewhat limited time. With this aim in view I have described the essentials of the subject in a straightforward manner, bearing in mind throughout that the reader wishes to study with the practical aim of becoming a pilot, navigator, or observer. In a few sections, slightly more advanced topics are introduced than many will need to study, but these sections are marked with an asterisk so that they may be omitted by any reader who wishes to learn only what is absolutely essential for ordinary navigational practice.

No useful knowledge of navigation can be acquired without much practical work in plotting on charts. Accordingly a large number of exercises will be found in this book, and a specially prepared chart is provided on which many of the exercises can be worked. I hope that the exercises will greatly increase the usefulness of the book to those who are learning navigation under a teacher, and they are quite essential for any reader who is studying the subject on his own.

The book is the fruit of considerable experience in the teaching of navigation, both in the Royal Navy during the last war, and, more recently, to A.T.C. Cadets, men on deferred R.A.F. service, and University Air Squadron Cadets. I am familiar with the requirements of all these types of student and have borne them in mind throughout the writing of the book, which covers and goes beyond the navigation at present studied in A.T.C. units and Initial Training Wings. Although, however, the needs of boys and men who intend to enter, or have already entered, the Royal Air Force have been given first

consideration, the book will serve equally well for beginners who have civil aviation in view.

Great care has been exercised to avoid errors in the text and in the answers to the examples, but I should be grateful for any corrections or suggestions any reader may be good enough to send me.

E. R. HAMILTON

ISLEWORTH
  June 1942

CONTENTS

ABBREVIATIONS

The following standard abbreviations will be used throughout this book :

a/c	Alter course	Mer. Parts	Meridional Parts
C	Compass	m.p.h.	Miles per hour
C.A.S.	Corrected Air-Speed	n.m.	Nautical miles
Ch. Lat.	Change of Latitude	P	Port
Ch. Long.	Change of Longitude	P/L	Position Line
Co.	Course	Posn.	Position
D.R.	Dead Reckoning	S	Starboard
E.T.A.	Estimated Time of Arrival	s/c	Set course
		st. m.	Statute miles
E.T.I.	Estimated Time of Interception	T	True
		T.A.S.	True Air-Speed
G.P.I.	Geographical Position of Interception	T.M.G.	Track Made Good
		Tr.	Track
G/S	Ground-Speed	T.T.T.	Time to Turn
I.A.S.	Indicated Air-Speed	W/D	Wind Direction
k.	Knots	W/S	Wind Speed
M	Magnetic	W/V	Wind Velocity

NOTE

An asterisk [*] indicates a harder section or question which may be omitted by beginners.

Throughout this book the letter [A] at the end of a question indicates that the question may be solved on the chart provided with the book. Letter [M] indicates that the question may be solved on a Mercator chart of North-West Europe, such as is used in the R.A.F. Questions which can be solved on either chart are marked [AM].

Additional copies of the Chart provided with this volume may be purchased separately. Price 6d. net.

INTRODUCTION

AIMS AND METHODS OF AIR NAVIGATION

Introductory : Navigation is the art of guiding an aircraft or a ship from one place to another. Upon the navigator's knowledge and skill depends to a large extent the success of all aviation, whether in peace or in war. Without navigation no aircraft could fly or ship cross the seas.

Success in navigation can come finally only from much practice at sea or in the air. But success also demands a clear understanding of the main ideas of the subject. Those ideas are not difficult : there is no black magic in navigation ; only common sense and a little, a very little, mathematics. The beginner who reads through this book carefully, and works the exercises (also carefully), will know all he needs of theory in order to make a start in practical navigation.

Instruments and Skill : The navigator is aided in his task by various instruments and he must know how to use these as readily and unthinkingly as he can turn a key in a lock. He must be familiar with the types of compass used to measure direction ; with the air-speed indicator which tells how quickly the aircraft is moving through the air ; with the altimeter which indicates the height of the aircraft. He need not have a detailed knowledge of the construction of such instruments but must know the general principles on which they work and be able to read them and apply the necessary corrections to the readings.

Throughout his work the navigator is using maps and charts. Here again he need not have a deep knowledge of how such things are constructed, but he must understand something of the principles underlying them or he will not

be able to use them. In this book sufficient, and no more, is said about the principles of maps and charts to enable the navigator to use them effectively.

Whether he is reading an instrument, such as an altimeter or a bubble sextant, or reading a map, or plotting with protractor and dividers on a chart, the navigator will be using skills which he must by constant practice make second nature. If he makes mistakes in the classroom he may make worse mistakes, with more serious consequences, in the air. The moral for the student is : Learn the essential ideas thoroughly and practise the skills constantly.

The Navigator's Job : The navigator's job is to decide in what direction to travel to get from one place to another, and to know as accurately as possible where he is at each moment of time during the journey. The whole of navigation is concerned with those two problems and with nothing else.

Before he sets out on a flight the navigator must decide what course to steer, making due allowance for wind, in order to reach his destination ; he must calculate the time he may expect to arrive and decide (by consulting the map of the country over which he is going to fly) what landmarks he should look out for on the way. Then, while the flight is in progress, he has to keep a continuous record of where the aircraft is, give instructions to the pilot as to the course to steer and the time the destination will probably be reached, check whether the wind is changing, and keep a log.

To keep and check his position during a flight the air navigator uses three methods : Map Reading, Dead Reckoning, and Position Lines.

Map Reading : From time to time, if possible, the navigator " pinpoints " the position of the aircraft. That is to say, he notices that some feature marked on his map (*e.g.* a bridge over a canal near a church) is immediately beneath him, and so fixes his position on the map. Maps and charts

have been prepared specially for the air navigator showing things he wants to know, such as the position of aerodromes, landing-grounds, wireless stations, overhead electric cables, marine lights, etc., as well as such things as hills, rivers, lakes, and towns.

Dead Reckoning : But the navigator may be unable (*e.g.* on a dark night or above cloud) to see ground features. Hence he cannot depend upon pinpointing, though he will make every use of it he can.

He therefore uses what is called Dead Reckoning. This consists in deducing where the aircraft is from the distances it is estimated to have travelled along the various paths it has followed since its position was last definitely known.

FIG. 1

Thus suppose that at 0900 hours (*i.e.* 9 a.m.) an aircraft is known to be at A (Fig. 1). Allowing for the aircraft's speed and for the wind (the direction and speed of which the navigator is supposed to know), it is estimated that during the hour 9–10 a.m. the aircraft travels 75 miles due east, then 50 miles due south, then 25 miles north-east, arriving at B. We call B the Dead Reckoning (abbreviation D.R.) Position at 1000 hours.
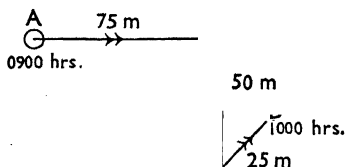
Position Lines : The navigator keeps his Dead Reckoning throughout the flight. But to find the D.R. position he has to assume that the wind has such and such a speed and direction. He may assume the wrong wind, or the wind may change during flight, so that it is important to apply checks to the D.R. position. This checking may be done by pinpointing or by obtaining what are called Position Lines.

A position line is a line on which, within the limits of error of the observation by which the line is obtained, an

aircraft is known to be situated at any particular time. Thus you may observe that a lighthouse is North-East of you. You will then be somewhere on a line running South-West from the lighthouse. That line can be drawn on the map and is a position line. Or a position line may be obtained by observing the direction in which wireless waves are coming from a transmitting station whose position is known.* Again (by methods described in Chap. X) an observation of a star will give a position line.

If we can obtain *two* position lines, on each of which we know the aircraft to lie at the same time, the actual position of the aircraft will obviously be where the lines intersect. A position obtained, by pinpointing or position lines, is called a Fix. The navigator from time to time obtains a fix as a check on his Dead Reckoning position.

The above brief description of a navigator's job will have made clear that some ideas, such as Position and Direction, are very important, and to them we shall now turn.

Advice to Student

(i) The exercises should be worked as they are reached before proceeding to the next topic.

(ii) Make your work neat, and as accurate as possible, from the first. Practice makes perfect, and if you practise *bad* habits you will make *them* " perfect."

(iii) If you intend to work your exercises in a book it should be a large one with plain paper, opening as flat as possible.

(iv) Things required :
    Medium-soft (HB) pencils
    Ruler, preferably graduated in millimetres
    Protractor graduated to 360°, preferably a " Douglas
        Protractor "
    Pair of dividers or compasses, preferably dividers
    Parallel rulers are very useful but not absolutely
        essential.

* See Chapter XI.

AIR NAVIGATION

CHAPTER I

POSITION ON THE EARTH

The Earth's Shape : For most purposes of navigation the Earth can be regarded as a " perfect sphere " ; that is, a solid like a billiard ball, of which every plane section is a circle.

A circle on the Earth such as A (Fig. 2), of which the plane passes through the Earth's centre, is called a GREAT CIRCLE. The centre of any great circle is the centre of the Earth, and the radius of the great circle is equal to the Earth's radius.
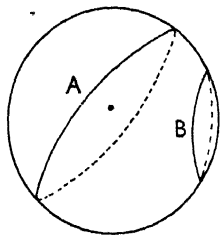
Any circle on the Earth whose plane does *not* pass through the Earth's centre (*e.g.* circle B in Fig. 2) is called a SMALL CIRCLE.

FIG. 2

Axis, Equator, Poles : The Earth rotates once a day about a diameter called the AXIS. The ends of the axis are called the TRUE POLES.
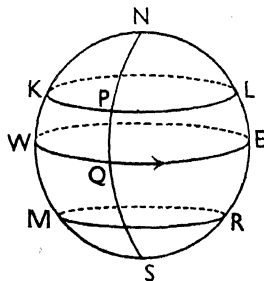
Face the direction (called " East ") towards which the Earth rotates and the pole on your left is called the North Pole, that on your right the South Pole.

The great circle WE (Fig. 3) which is midway between the poles, and whose plane is perpendicular to the Earth's axis, is called the EQUATOR.

FIG. 3

Meridians and Parallels : Any semi-great circle joining the poles (such as NQS in Fig. 3) is called a TRUE MERIDIAN, or, when there can be no confusion, just a " Meridian."

A small circle parallel to the Equator (such as KL or MR, Fig. 3) is called a PARALLEL OF LATITUDE, or just a " Parallel."

The importance of meridians and parallels is due to the fact that through any point, such as P in Fig. 3, just *one* meridian (NPS) and *one* parallel (KPL) can be drawn. Thus by naming the meridians and parallels we can describe the position of P on the Earth's surface. This is done as follows.
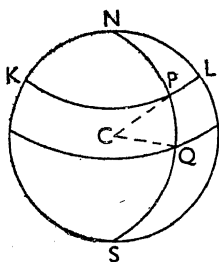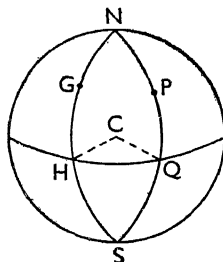
FIG. 4   FIG. 5

Latitude : The Latitude of P (and of any point on the parallel of P) is the arc, PQ, of the meridian between the parallel and the Equator (Fig. 4). Latitude is measured in degrees of angle, from 0° at the Equator to 90° at either pole, and is named North or South according to whether the parallel is north or south of the Equator. In Fig. 4, KL (and, therefore, P) has North Latitude.

If C is the centre of the Earth, angle PCQ is the latitude of P and of the parallel KL.

Longitude : The Longitude of P (and of any point on the meridian of P) is the shorter arc, HQ, of the Equator between the meridian and a standard meridian (NHS), called the Prime Meridian (Fig. 5). The Prime Meridian passes

through Greenwich Observatory, G. Longitude is measured in degrees from 0° to 180°, and is called East or West according to whether the meridian in question is east or west of the meridian of Greenwich. In Fig. 5 the meridian of P has East Longitude.

If C is the centre of the Earth, angle HCQ is the longitude of the meridian NQS.

Suppose in Fig. 5 angle PCQ is 47°, while angle HCQ is 68°. Then we should say that P was the point 47° North, 68° East.

Degrees and Minutes : A degree of latitude, or of longitude measured along the Equator, is about 70 miles long. So we need units of angle smaller than degrees in stating latitudes and longitudes. We use *minutes,* there being 60 minutes (60′) in 1 degree.

Thus, a point somewhat North and East of P in the example in the previous paragraph might have the position 47° 18′ N., 68° 39′ E.

If still greater accuracy is required, *seconds* of angle are introduced, there being 60 seconds (60″) in 1′. Thus P might be the point 47° 18′ 30″ N., 68° 39′ 54″ E.

It is a common, but not invariable, practice to write in latitude and longitude two figures for the number of degrees (three for longitudes greater than 90°), two figures for the minutes, and two for the seconds. Thus longitude 6 degrees 12 minutes West would be written 06° 12′ W. We could, therefore, if we wished, omit the degree and minute signs, though this is not yet generally done, and write 0612W for 06° 12′ W. *Minutes* of latitude and longitude should *always* be written with two figures.

Nautical Miles : All great circles are the same size, having a radius equal to that of the Earth. Hence a great-circle arc which subtends, say, an angle of 1′ to the Earth's centre is of a definite length, and the length will be the same wherever on the Earth's surface the arc is situated. A great-circle arc

which subtends 1' of angle at the Earth's centre is said to be
1 NAUTICAL MILE long. Thus a minute of latitude, or a
minute of longitude *on the equator*, is 1 nautical mile long.
It is often more convenient for navigators to use nautical
than statute miles. A nautical mile (written 1 n.m. or 1')
is about 6080 ft. long, being therefore greater than the
statute mile of 5280 ft.

To convert nautical into statute miles, or *vice versa*, note
that
$$\frac{1 \text{ nautical mile}}{1 \text{ statute mile}} = \frac{6080}{5280} = \frac{76}{66}$$

Thus 76 statute miles = 66 nautical miles.

A *speed* of 1 nautical mile an hour is called a KNOT.

Change of Latitude and Longitude
It is sometimes necessary to find by how much one's latitude
and longitude will change during a flight.*

(i) *Change of Latitude :* The Change of Latitude between
two places, such as F and T in Fig. 6, is the arc of the meridian
between the parallels of the two places.
That is, Change of Latitude (abbrev.
Ch. Lat.) = arc FA or arc BT. If the
latitude of F is 53° 16' N. and that of T
is 39° 12' N., clearly

FIG. 6

Ch. Lat. = 53° 16' — 39° 12'
       = 14° 04'.

Since the change is southerly † we
say that it is 14° 04' S.

In this case the latitudes of F and T
are both North. By drawing a diagram
you can convince yourself that if the latitudes were of
" opposite names," that is, one of them North, the other
South, you would have to *add* the latitudes to find the Ch. Lat.

* For example, in calculating the track between two places (see p. 57),
or in finding a " Conversion Angle " (see p. 154).
† Assuming we travel *from* F *to* T.
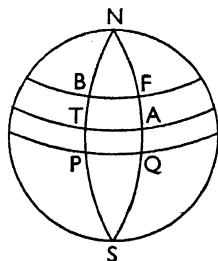
(ii) *Change of Longitude* : The Change of Longitude from one place to another is the *smaller* arc of the Equator intercepted between the meridians of the two places. Thus the Change of Longitude (Ch. Long.) from F to T (Fig. 6) is the arc QP.

Suppose Long. F = 15° 52′ W. and Long. T = 45° 07′ W.

Clearly Ch. Long. = QP = 45° 07′ — 15° 52′
= 29° 15′ W.

The Ch. Long. is named West in this case because the movement is westwards.

In this example the longitudes of F and T are both West. A little thought will show you that if the longitudes had been of opposite names (one East, the other West) you would have had to add them to find the Ch. Long.

For both Ch. Lat. and Ch. Long. the rule is

Same names Subtract, Opposite names Add

The importance of remembering that Ch. Long. is the *smaller* arc of the Equator between the meridians is seen from the following example :

Find the Ch. Long. from F (174° 20′ E.) to T (168° 30′ W.)

Long. F	174° 20′ E.	
Long. T	168° 30′ W.	
Ch. Long.	342° 50′ W.	(opposite names add)
Ch. Long.	17° 10′ E.	(*i.e. smaller* arc of Equator)

Compare this calculation with Fig. 7, which is a view from above the North Pole, so that meridians are represented by radii.

It is important for the navigator to be able to add and subtract in angular units and some exercises will be found below.
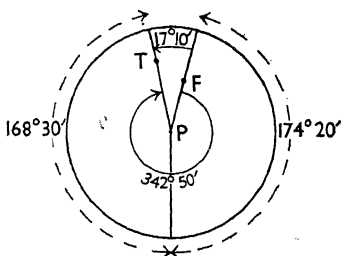
FIG. 7

EXERCISE I

1. Draw a circle to represent the Earth and mark on it :
North and South Poles ; Equator ; a parallel of North
latitude ; a parallel of South latitude ; a small circle which
is not a parallel of latitude. Show by an arrow on the Equator
the direction in which the earth turns.

2. On a circle to represent the Earth mark :
North and South Poles ; the Prime (Greenwich) Meridian ;
a meridian of West longitude ; a meridian of East longitude ;
a great circle which is not the Equator and not a meridian.

3. From atlas maps find the latitude and longitude of :
Boston (Lincs.), Buckingham, Hamburg, Benghazi, New
York, Sydney.

4. Find the sum of (a) $38° 14'$ and $21° 39'$; (b) $12° 45'$ and
$11° 56'$; (c) $81° 09'$ and $09° 52'$.

5. Find the difference between (a) $28° 17'$ and $12° 09'$;
(b) $75° 28'$ and $51° 42'$; (c) $62° 04'$ and $53° 37'$.

6. Find
(a) $49° 36' 27'' + 34° 29' 14''$; (b) $12° 06' 48'' + 56° 52' 18''$.

7. Find
(a) $49° 36' 27'' - 34° 29' 14''$; (b) $14° 35' 05'' - 11° 38' 55''$.

8. An aircraft flies the following distances in Statute Miles :
$38 + 4 + 59 + 159$. Find the total distance travelled in
nautical miles.

9. An aircraft flies the following distances in Nautical Miles :
$43 + 74 + 2 + 11$. Find the total distance travelled in
statute miles.

10. Doncaster and Leicester each have longitude $01° 08'$ W.
The latitude of Doncaster is $53° 31'$ N., that of Leicester
is $52° 38'$ N. Find the distance between these two towns in
nautical miles. Then find the distance in statute miles.

11. Copy and complete this table :

Lat. F	Lat. T	Ch. Lat. F to T	Long. F	Long. T	Ch. Long. F to T
51° 20′ N.	57° 15′ N.		19° 08′ W.	31° 17′ W.	
25° 15′ N.	12° 04′ N.		22° 51′ W.	25° 09′ W.	
15° 18′ S.	26° 19′ S.		14° 06′ W.	31° 42′ W.	
32° 08′ S.	29° 26′ S.		120° 16′ E.	124° 22′ E.	
05° 43′ S.	11° 52′ N.		152° 18′ E.	150° 04′ E.	
12° 14′ N.	02° 17′ N.		15° 08′ W.	06° 15′ E.	
13° 28′ N.	11° 44′ S.		25° 31′ E.	12° 16′ W.	
60° 18′ N.	63° 52′ N.		178° 14′ W.	177° 42′ E.	

CHAPTER II

DIRECTION ON THE EARTH

In a Garden: If you want to measure the direction of various points in a garden from, say, the centre of the garden, you must have a standard direction from which to measure. The standard direction is True North, that is, the direction of the North Pole from the observer. We use North as standard direction, whether we are situated in the North or in the South hemisphere of the Earth. In Fig. 8, ON shows
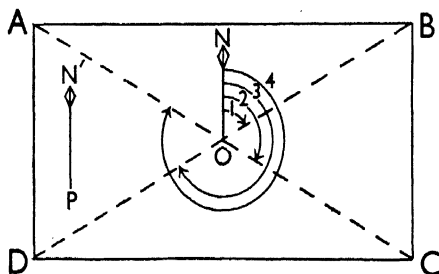
FIG. 8

the standard direction at O in the garden ABCD. Clearly ON is part of the True Meridian of O.

We measure all directions *in angle clockwise from the meridian,* always stating the angle in three figures.

Thus, if angle NOB = 62°, the direction (" bearing ") of B from O is 062°.

The angle shown by arrow 2 is 118°, so that C bears 118° from O.

Angle 3 is 242°, and D bears 242° from O.

A bears 298° from O.

On the Earth's Surface : True North at any point, such as
P, in the garden in Fig. 8 will be parallel to True North at O,
for the garden is very small compared
with the distance of the North Pole.   But
if you take two places, such as O and P
in Fig. 9, which are a long way apart,
it is obvious that True North at O is not
parallel to True North at P, for the
meridians converge towards the pole.
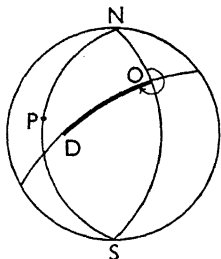
FIG. 9

Moreover, in the garden the join of
O and, say, D is a straight line.   But if
D is a long way from O, as in Fig. 9, we
cannot draw a straight line on the Earth's
surface, which is curved, from O to D.   So, in order to find
the direction of D from O we join the points by a *great-circle
arc* (the part of the great circle on the near side of the Earth
is shown in the figure) and measure the clockwise angle
shown by the arrow at O.

The TRUE BEARING of one place (such as D) from another
place (such as O) is the direction at
O (measured clockwise in angle from
the meridian at O) of the great-circle
arc from O to D.
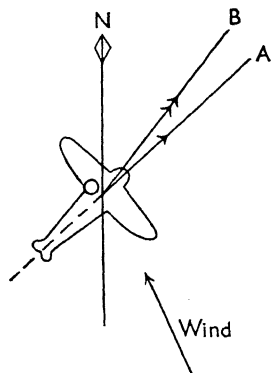
FIG. 10

Courses and Tracks : The direction
in which an aircraft is heading is
called the course.   The COURSE is
the angle (measured clockwise) from
the meridian to the axis of the air-
craft.   That is, in Fig. 10, angle
NOA.

In still air the aircraft moves
over the ground in the direction of
the course.   But if there is a wind
(other than a head or tail wind) the actual path of the air-
craft over the ground will be along some direction, such as

OB in the figure, other than the course. This direction of motion over the ground is called the Track. Track is the angle (measured clockwise) from the meridian passing through the aircraft to the direction along which the aircraft is moving over the ground. In Fig. 10, Track = angle NOB.*

Rhumb Line

A Rhumb Line is a line on the Earth's surface cutting all meridians at the same angle. The path of an aircraft which moves on a constant track is a Rhumb Line. In Fig. 11
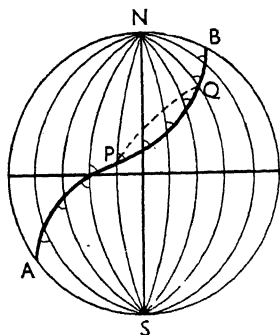
Fig. 11

AB is a rhumb line, all the angles marked being equal. If this angle were, for example, 55°, an aircraft flying from A to B would be on the track 055° all the time.

As a rule ships and aircraft travel along rhumb lines. Although the great circle, and not the rhumb line, between two places is the shorter route, it is more convenient to keep on the constant track represented by the rhumb line. Notice in Fig. 11 that the great circle path between P and Q (shown by the broken line) cuts the various meridians at different angles, so that an aircraft following the great-circle track would have to be constantly changing the direction of its motion.†

* Note that Track is an *angle*. If we wish to mention the actual line on the Earth's surface over which the aircraft moves we may refer to it as the " track-line," or better as the *Path* of the aircraft. It is unfortunate that the term Path is not in general use.

† For places of approximately the same latitude, and some distance from the equator, there may be a considerable difference between the rhumb-line and great-circle distances. Thus the rhumb-line distance in nautical miles from Tokyo to San Francisco is 4858, while the great-circle distance is 4502. On the other hand, for Berlin and Cape Town, which

A rhumb line is always *concave*, a great circle always *convex*, towards the nearer pole (see Fig. 11).

Particular cases of rhumb lines are : Meridians, Parallels, the Equator.

EXERCISE II A

1. Draw a line to represent the true meridian at a place O, marking the North end with a diamond as in Fig. 8. Then from O draw lines running in the following directions : 055°, 120°, 194°, 330°.

2. Express each of the following directions by the three-figure clockwise method : N., N.E., E., S.E., S., S.W., W., N.W.

3. (*a*) How many degrees west of South is the direction 220° ?
   (*b*) How many degrees west of North is the direction 310° ?

4. What is the opposite (usually called the " reciprocal ") direction to 142° ? What is the reciprocal direction to 324° ?

5. You are walking in direction 257° and turn through 35° to the left. In what direction are you now walking ?

6. Make a sketch showing an aircraft on Course 220° with Track 228°. Show by an arrow roughly the direction in which the wind is blowing.

7. What lines on the Earth's surface are both rhumb lines and great circles ?

differ little in longitude, the rhumb-line distance is practically equal to the great-circle distance. Other examples : New York to Cape Town (rhumb 6807, great circle 6780) ; Cape Town to Singapore (rhumb 5267, great circle 5216).

An illustration of the change of track along a great circle is provided by the journey from Cape Town to Singapore. This great circle cuts the meridian of Cape Town at 86°, that of Singapore at 56°, so during the journey the track changes from 086° to 056°.

Magnetic North: Since directions are measured from the North it is necessary to have an instrument which will indicate the direction of North. The instrument used in aircraft for this purpose is the magnetic compass.

Magnets behave as though there were two kinds of magnetism, one kind concentrated at one end of the magnet, the other kind at the other end. We call the end where one kind of magnetism is situated the " Red " end, the other end the " Blue " end of the magnet. If two magnets are brought near one another, red ends (red " poles ") repel one another, blue poles repel one another, but blue poles attract red poles.

The Earth itself is an irregular magnet with its blue pole in the Arctic regions but not at the True North Pole. Consequently if a magnetized needle is freely suspended, its red pole, attracted by the Earth's blue pole, will turn towards North. But the magnetic needle will not usually point to *True* North. The direction in which the needle points is called *Magnetic North.*

In order to use a magnetic compass to measure True directions we must know by how much Magnetic North differs from True North. The difference between Magnetic North and True North at any place is called VARIATION. Variation is measured in degrees and is named East or West according to whether Magnetic North is East or West of True North. The Variation for any place is to be found on maps and charts (see p. 35). Variation changes slowly from year to year.

Conversion of Directions

(i) Westerly Variation. Consider a bearing taken with a magnetic compass at Heston in the year 1942. The Magnetic bearing of A from H is found to be 150° (Fig. 12). What is the True bearing ?

Variation is found from the map to be 10° W.

$$\text{Magnetic bearing} = \text{angle MHA} = 150°$$
$$\text{Variation} = \quad 10°\,\text{W}$$
$$\text{True bearing} = \text{angle NHA} = 140°$$

Using T for " True " and M for " Magnetic " we should set out the sum thus :

Bearing 150° M
Var.   10° W
Bearing 140° T

To convert a *True* bearing into a *Magnetic* bearing the process is reversed. Thus Fig. 13 shows a True bearing of 240° converted into a Magnetic bearing, the Variation being 12° W.
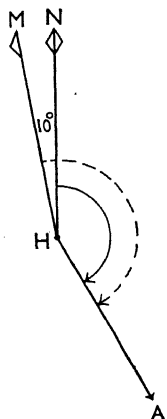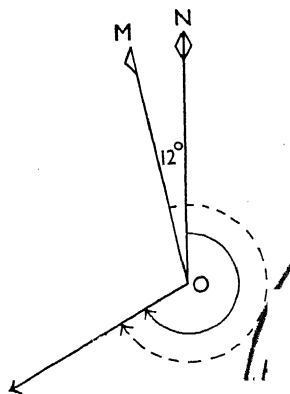
FIG. 12   FIG. 13

True bearing of A from O
= unbroken arrow = 240°.
Magnetic bearing
= broken arrow = 252°.
Set out thus :   Bearing 240° T
                  Var.   12° W
                  Bearing 252° M

(ii) Easterly Variation. The following two sums illustrate the method. Compare them with the diagrams, and note the

conventional way of marking True and Magnetic North with a diamond and half-diamond respectively.

(*a*) Magnetic to True (Fig. 14).

$$\begin{array}{ll}
\text{Bearing} & 051° \text{ M} \\
\text{Var.} & 8° \text{ E} \\
\hline
\text{Bearing} & 059° \text{ T}
\end{array}$$
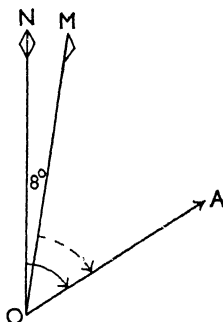
FIG. 14

(*b*) True to Magnetic (Fig. 15).

$$\begin{array}{ll}
\text{Bearing} & 147° \text{ T} \\
\text{Var.} & 8° \text{ E} \\
\hline
\text{Bearing} & 139° \text{ M}
\end{array}$$
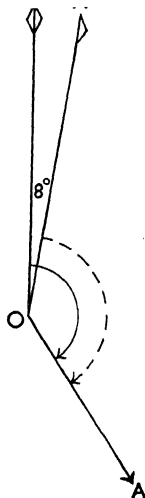
All these rules can be briefly stated thus :

Magnetic Bearing (or Course) is *Greater than* True if Variation is Westerly.

Magnetic Bearing (or Course) is *Less than* True if Variation is Easterly.

Or, as it is sometimes still more briefly stated :

Variation West, Magnetic Best ;
Variation East, Magnetic Least.

FIG. 15

EXERCISE II B

1. (a) Draw a figure to show True North and Magnetic North when the variation is 13° W. Write 13° in the angle which shows the variation.

(b) On the same figure show a Magnetic bearing of 075°. What is the corresponding True bearing ?

2. (a) Draw a figure to show True North and Magnetic North when the variation is 11° E., writing 11° in the angle which shows the variation.

(b) On the same figure show a Magnetic bearing of 214°. What is the corresponding True bearing ?

3. Make a sketch showing variation 10° W. and a True bearing of 324°.   Find the Magnetic bearing.

4. By means of a sketch find the Magnetic bearing corresponding to True bearing 148°, the variation being 8° E.

5. Copy and complete the following :

Variation .	11° W.	9° E.	10° E.	14° W.	8° W.	10° E.	13° W.	7° E.
Magnetic bearing .		323°	215°	134°	317°			
True bearing						043°	158°	300°	255°

6. Copy and complete the following :

Variation . .	16° E.	12° W.	14° E.	15° W.
Magnetic bearing	355°	009°		
True bearing .			012°	349°

7. Copy and complete the following :

Variation . .				
Magnetic bearing	036°	137°	353°	012°
True bearing .	052°	128°	008°	358°

Compass North : The needle of a compass in an aircraft or ship does not usually point exactly to Magnetic North. The metal of the craft deflects, or " deviates," the needle to East or West of Magnetic North. The direction in which the compass needle of an aircraft points is called COMPASS NORTH, and the difference between Compass and Magnetic North is called DEVIATION. If the compass needle points East of Magnetic North the deviation is Easterly, if the compass needle points West of Magnetic North the deviation is Westerly.

Unlike variation, which depends solely upon the part of the world in which the aircraft is situated, deviation depends upon the construction of the particular aircraft in which the
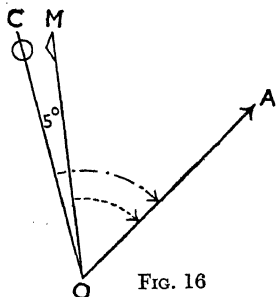
FIG. 16

compass is placed, and upon the course of the aircraft. (See p. 36 below.) For any particular aircraft it is found by trial what the deviation is for various courses, and the deviations are recorded in a table.

We convert Compass bearings into Magnetic bearings by a method similar to that for converting Magnetic into True or *vice versa.*

In Fig. 16 OC shows Compass North at O, OM shows Magnetic North. The deviation is 5° W.

$$\text{Compass bearing of A} = 060° \text{ (say)}$$
$$= \text{angle COA}$$
$$\text{Magnetic bearing of A} = \text{angle MOA} \quad \cdot$$
$$= 055°$$

Thus, to turn a Compass bearing into a Magnetic bearing we have to *subtract Westerly Deviation*.

You can draw a diagram to show that to turn Compass into Magnetic bearing we have to *add Easterly Deviation*.
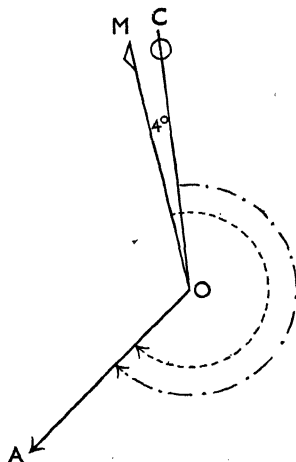
FIG. 17

The opposite process—turning a Magnetic into a Compass bearing—is illustrated in Fig. 17 and in the following sum :

$$
\begin{array}{ll}
\text{Bearing of A} & 238°\ \text{M} \quad \text{(say)} \\
\text{Dev.} & \underline{\quad 4°\ \text{E}} \\
\text{Bearing of A} & 234°\ \text{C}
\end{array}
$$

The following rhyme, corresponding to the one for Variation, is useful :

Deviation West, Compass Best ;

Deviation East, Compass Least.

3

To convert a Compass bearing into a True bearing we first apply Deviation, so obtaining the Magnetic bearing, then apply Variation, so obtaining the True bearing.

To convert True bearings to Compass reverse the process : apply Variation first, then Deviation.

The following may help you to remember this :

Compass } ◄——— Deviation   - Magnetic } ·   · Variation   - { True
Bearing } ——►   Bearing } -   ——► { Bearing

An example of each process, with the corresponding figure, is given below :

(i) Convert 130° C to True, given Dev. = 5° W., Var. = 14° W.

$$
\begin{array}{ll}
\text{Bearing} & 130° \text{ C} \\
\text{Dev.} & 5° \text{ W} \\
\hline
\text{Bearing} & 125° \text{ M} \\
\text{Var.} & 14° \text{ W} \\
\hline
\text{Bearing} & 111° \text{ T}
\end{array}
$$
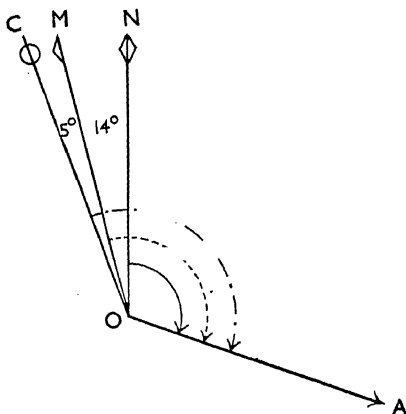
FIG. 18

(ii) Convert 285° T to Compass, given Var. 15° W., Dev. = 5° E.

$$
\begin{array}{ll}
\text{Bearing} & 285° \text{ T} \\
\text{Var.} & 15° \text{ W} \\
\hline
\text{Bearing} & 300° \text{ M} \\
\text{Dev.} & 5° \text{ E} \\
\hline
\text{Bearing} & 295° \text{ C}
\end{array}
$$
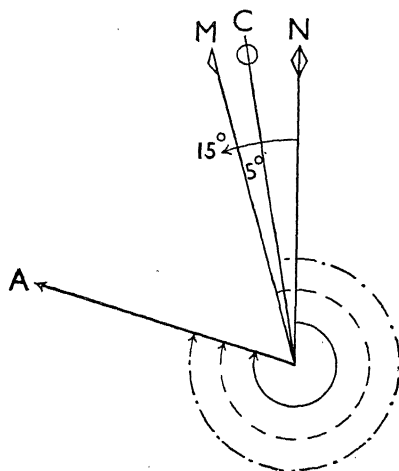
Fig. 19

Variation on Maps : Variation is due to the magnetism of the Earth and it differs in different parts of the world. Thus at present (1942) the variation is 10° W. in London, 24° at Cape Town, and 16° E. in New Zealand. Variation is indicated on maps and charts by one or other of several methods, all of which are obvious when you examine the chart. The most convenient method is by means of lines (called " Isogonals ") of equal variation drawn across the chart (see Chart A).

Variation changes slowly from year to year, and the rate

of its change is stated on maps and charts. Thus on each of the isogonals on Chart A you read what the variation is for 1942 and by how much it is changing annually. This is necessary since the chart may be used some years after it was issued and the variation has then to be corrected accordingly when you read it off the chart.

For purposes of navigation it is always sufficient to read variation off a map to the nearest ½ degree, and usually the nearest 1° will suffice.

Deviation : The magnetic material of an aircraft may be very irregularly distributed, but for simplicity suppose the
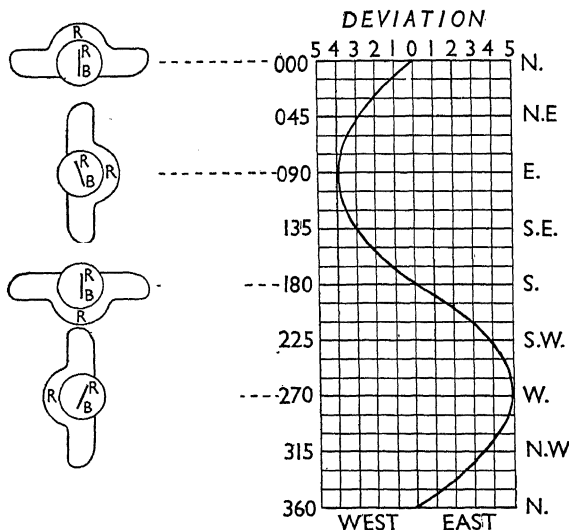
FIG. 20

aircraft's magnetism is equivalent to a red pole in the nose and a blue pole in the tail. Then (see Fig. 20) when the aircraft is heading North Magnetic the red pole in the nose weakens the effect of the Earth's magnetism but, since both

Earth's and aircraft's magnetic forces are in the same line, the needle will not be deflected from Magnetic North. There will be no deviation on a course 000° M.

When the aircraft heads East Magnetic the red pole in the nose will repel the red pole, and attract the blue pole, of the needle, producing Westerly deviation.

On course South Magnetic the effect of the aircraft's magnetism is merely to strengthen the Earth's pull on the needle. No deviation, therefore, on this course.

On course 270° M the aircraft's magnetism will produce Easterly deviation.

On intermediate courses the deviation will be as shown by a curve somewhat like that shown in Fig. 20. Such a curve is worked out by observation for each aircraft, and is placed in the aircraft near the compass. Sometimes, instead of being shown in a curve as in Fig. 20, the deviations are tabulated on a small card.

By placing small magnets near the compass to counteract the magnetism of the aircraft, it is possible to reduce the deviation on all courses to a few degrees.

In Fig. 20 the deviation is plotted for various *Magnetic* Courses. If we know the magnetic course we can at once find the deviation and so calculate the compass course. If, however, we know the *compass* course and wish to find the deviation, we can still use the same deviation curve. To understand this, suppose we want to find the magnetic course corresponding to a compass course 150°, using the deviation curve shown in Fig. 20. Since the compass course differs from the magnetic by only a few degrees we look up the deviation for a *magnetic* course of 150°. Dev. = 2° W. Applying deviation 2° W. to compass course 150°, we find as equivalent magnetic course 148°. Now, the deviation for a magnetic course 148° is to all intents and purposes the same as that for a magnetic course of 150°, so that it was quite in order to look up the deviation for magnetic course 150°, although actually the 150° was compass course. Deviations,

then, can be taken from a Deviation Curve or Table for either Compass or Magnetic Courses.

Note carefully :

(i) Variation depends solely upon your position on the Earth's surface, and has nothing to do with the particular aircraft in which you are flying.

(ii) Deviation depends upon the particular aircraft in which you are flying and upon the course of the aircraft.*

A navigator frequently takes compass bearings of landmarks. It is important to remember that, when converting such bearings from Compass to True, we must use the deviation for *the course of the aircraft*, not for the bearing.

EXERCISE II C

1. In rough sketches show True, Magnetic, and Compass north for (*a*) Var. 12° W., Dev. 4° W. ; (*b*) Var. 15° W., Dev. 3° E. ; (*c*) Var. 8° E., Dev. 2° E. ; (*d*) Var. 10° E., Dev. 5° W.

2. Copy and complete :

Compass bearing	058°	169°		
Magnetic bearing			315°	142°
Deviation . .	4° W.	2° E.	5° E.	3° W.

* Deviation depends upon the strength of the Earth's magnetic force as compared with that of the aircraft. If the aircraft is moved a considerable distance, so that there is an appreciable difference between the strength of the Earth's magnetic force in the new position of the aircraft as compared with the old, then deviation will be affected and a new Deviation Curve must be constructed. Also, in course of time the magnetism of the aircraft changes, and it is therefore necessary to check up deviation frequently (once every month or so if possible).

3. Using sketches, or in any other way, convert the following Compass bearings into True bearings :

Compass bearing	265°	154°	287°	248°
Deviation . .	3° W.	3° E.	4° E.	5° W.
Variation . .	11° W.	16° E.	14° W.	17° E.

4. Convert the following True bearings into Compass bearings :

True bearing	195°	054°	306°	164°
Variation .	12° W.	15° E.	13° W.	10° E.
Deviation .	5° W.	2° E.	1° E.	4° W.

5. On Chart A find the variation at the following places in the year 1942 : EXETER, JERSEY, CARDIFF.

6. Using Chart A, find the variation for the following :

Place :	SOUTHAMPTON	LAND'S END	LE HAVRE
Year :	1945	1948	1944

7. The compass course of an aircraft which is passing over LIZARD HEAD in year 1942 is 148°. Using the Deviation table at the beginning of the book* (page ii), find the True course.

* Throughout this book in all questions involving deviation the curve on p. ii should be used unless there are instructions to the contrary. Variation should be for 1942 unless there are instructions to the contrary.

CHAPTER III

MAPS

Introductory : The air navigator makes much use of maps both in planning a flight and during the flight itself. He needs to know the signs and symbols used to represent various features such as hills, aerodromes, lights, etc. No explanation of these signs is necessary ; the more important must just be learnt by heart. He must practise interpreting the map of the country over which he is flying so that he can translate the map into the panorama that spreads beneath him. But he must also understand something of the principles on which the map is constructed, and the little he need know of those principles is explained in this chapter.

Inaccuracy of Maps : The only map of the world which can truly represent the shapes and sizes of lands and seas is one drawn on a globe. For, since you cannot wrap up a ball in paper without crinkling the paper, an exact representation of the round Earth cannot be drawn upon flat paper. In making a map we have, therefore, to sacrifice something—we cannot in one and the same map correctly represent shape, area, distances, angles, and all the other features. But we have a choice as to what we shall sacrifice, and we make the choice according to the particular uses to which we wish to put the map.

The Graticule

How can we construct a map ? We have seen that the position of any point on the Earth's surface is known if we know the latitude and longitude of the point. If, for example,

we knew the latitudes and longitudes of a large number of points on a coastline we could plot the points on a terrestrial globe, and obtain a globe-map of the coastline by joining them up.   Similarly, if we could draw the meridians and parallels according to some plan on a piece of paper, and then plot the latitudes and longitudes of the points on the coastline on the paper, we should get a flat map of the coastline.

The network of lines representing, according to some plan, the meridians and parallels, is called a Graticule.   There are many plans we could adopt, all leading to different graticules. If we want to understand the principles on which any particular map is constructed we study its graticule.   There are only two graticules with which the air navigator need be familiar, one described in this chapter, the other in the next.

Topographical Maps

These are maps showing towns, rivers, hills, aerodromes, lights, overhead cables, and other features in which the air navigator is interested.   Most topographical maps are now drawn on a graticule which goes by the alarming name of the Modified Polyconic Projection.*

The graticule of this kind of map is very simple (see Fig. 21) :

(i) Meridians are straight lines converging towards the pole.
(ii) Parallels are curved, and the distance between successive parallels is constant ; that is to say, in Fig. 21, AB = BC = CD, etc.

The chief properties of any map drawn on this scheme are as follows :

(a) Straight lines on the map represent great circles on the Earth's surface.

Thus PQ in Fig. 21 represents the great circle track from P to Q.   It therefore represents the shortest distance from

---

* A projection called Cassini's is also used, but it differs only slightly from the Polyconic.
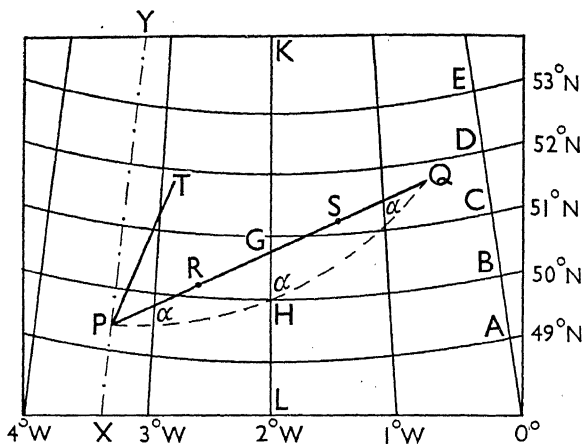
Fig. 21

P to Q on the Earth's surface, and, being straight, it is also the shortest distance between P and Q on the map.

(*b*) The scale is the same at all points of the map.

Thus, if PR is 6 in. long and represents 24 miles, and SQ is also 6 in. long, then SQ represents 24 miles. If PR is 9 in. long it will represent 36 miles. This will not surprise most people, because the best-known maps are constant-scale topographical maps. But it is *not* true of the Mercator map, which will be studied in the next chapter.

(*c*) Angles are correctly represented.

Thus the angles the straight line PQ makes with the meridians 3° W., 2° W., and 1° W. on the map are equal to the angles the great circle arc PQ makes with the meridians on the Earth's surface. Or, if P, Q, and T are three towns, the angle TPQ on the map is equal to the angle between the great circle arcs PT and PQ on the Earth's surface.

Note that since the angle between any meridian and a parallel is a right angle on the Earth's surface the same will be true of the meridians and parallels on the map.

(*d*) Rhumb lines are represented by curves (concave to the near pole).

In Fig. 21 the broken line represents the rhumb line from P to Q. Since angles are correctly represented on the map the broken line cuts all the meridians at the same angle (α).

Scale

The scale of a topographical map may be stated in the following ways :

(i) By a statement in words, *e.g.* " 1 inch to 4 miles."

(ii) By a scale line, *e.g.*

Furlongs 0   1 Miles 2

Sometimes the border of the map is graduated to show statute miles.

(iii) By a " Representative Fraction." This is the ratio of any length on the map to the corresponding length on the Earth's surface. Thus, since there are 63,360 inches in 1 mile, the Representative Fraction (R.F. for short) of a map on a scale of 1 inch to 1 mile is 1/63,360.

Topographical maps in common use for air navigation are those with R.F.'s of 1/500,000 and 1/250,000. The former is usually referred to as a " half million map," the latter as a " quarter million map."

Example 1 : How many miles to the inch are there in a map of which the R.F. is 1/126,720 ?

1 in. on the map represents 126,720 in. on the ground.

$$126{,}720 \text{ in.} = \frac{126{,}720}{63{,}360} \text{ miles}$$
$$= 2 \text{ miles}$$

The scale of the map is therefore 1 in. to 2 miles.

Example 2 : What is the R.F. of a map on a scale of 6 in.
to 1 mile ?   6 in. on the map represents 63,360 in. on the
ground.   Therefore

$$\text{R.F.} = \frac{6}{63,360} \quad \frac{1}{10,560}$$

Latitude and Longitude

The accurate way to read off the latitude and longitude of a
point such as P on a topographical map (see Fig. 21) is as
follows :

Arrange a straight edge to pass through P and points X
and Y, on the South and North border of the map respectively,
so that X and Y have the same longitudes on the longitude
scales.   Then the longitude of X or Y will be that of P.

If the map is too large for this to be practicable, the
straight edge should be set through P parallel to the nearest
marked meridian, and the longitude read off where the straight
edge cuts either the North or the South border of the map.

The latitude of P will be 49° plus the number of minutes
of latitude in ZP, if Z is where XY cuts parallel 49° N.

Tracks on a Topographical Map

True bearings are angles between meridians and great circles.
On the topographical map great circles are represented by
straight lines.   Hence it is a simple matter to draw lines of
bearing on such a map.   Thus, suppose the true bearing of
Q from P is 065° (Fig. 21).   Then if XY is the meridian
of P the angle XPQ will be 65°.   Or, to draw a line showing
bearing 030° from P (*e.g.* the bearing of T, say) we simply
draw a straight line PT making angle 30° with PY.

But rhumb lines are not so easy to draw on this kind of
map, which is the main reason why such a map is not usually
employed in navigational plotting.   Suppose we want to fly
from P to Q (Fig. 21).   What rhumb-line track must we
follow ?   The only way we can answer that question by means
of a topographical map is to use the fact that for flights up

to a few hundred miles the great-circle track (PGQ in the figure) does not differ very greatly from the rhumb-line track (PHQ). (In order to show the rhumb line clearly its difference from the great circle is exaggerated in the figure.) So we draw the straight line PQ on the map and regard this as the path of the aircraft. We take as the measure of the track the angle KGQ at which PQ cuts the central meridian KL. This angle will be very nearly equal to the correct rhumb-line track α, for the rhumb line at H is nearly parallel to PQ.

Time-Distance Scales

When using a topographical map during a flight it is convenient to have a time-distance scale which indicates what length is covered on the map in a given time at a given ground-speed.*

Such a scale may be constructed as follows for a map of which the scale is uniform over the map. (No time-distance scale can be constructed for a map, such as Mercator's, of which the scale is non-uniform.)

Example : Construct a time–distance scale for a 1/250,000 map, for ground speeds ranging from 120 m.p.h. to 200 m.p.h.

$$\text{Distance travelled in 5 min. at 120 m.p.h.} = \frac{120}{12} \text{ m.}$$

$$= 10 \text{ m.}$$

$$\text{On 1/250,000 map 10 m. is represented by } \frac{10 \times 63,360}{250,000} \text{ in.}$$

$$= 2\cdot534 \text{ in.}$$

The distance covered on the map in 5 min. at 200 m.p.h.

$$= 2\cdot534 \times \frac{200}{120} \text{ in.}$$

$$= 4\cdot22 \text{ in.}$$

---

* " Ground-speed " is the speed at which the aircraft moves over the ground.

Draw AD (Fig. 22)* to any convenient scale, to represent speeds. Thus we may make AD = 3·2 in. long, and divide it into 16 parts as shown.
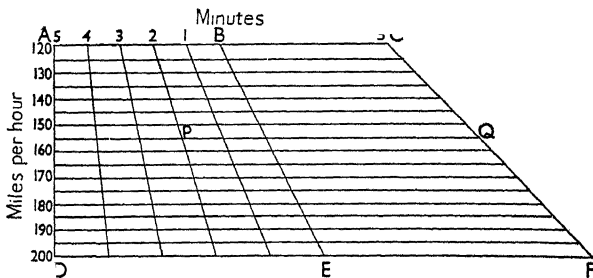
FIG. 22

At A draw AB, perpendicular to AD, and 2·53 in. long. Continue AB to C, making AB = BC.
At D draw DE, perpendicular to DA, and 4·22 in. long. Continue DE to F, making DE = EF.
Divide AB into five equal parts, and DE into five equal parts. Join the subdividing points as shown.
The scale is now complete.
As an illustration of the use of the scale, suppose the ground speed of the aircraft is 155 m.p.h. How far shall we travel on our map at that speed in 7 minutes ?
The answer is given by the length PQ (Fig. 22).
We need not know what that length is in inches, or how many miles it represents. We open the dividers to PQ and lay off the length along the track-line from our position at the beginning of the 7 minutes.
Those who are interested can discover why the time-distance scale works. They need only apply a little knowledge of similar triangles. The best plan is to imagine DA and EB produced upwards till they meet.

* Fig. 22 is on one-third scale.

EXERCISE III

1. On any topographical map test whether (a) the meridians are straight, (b) successive parallels are equidistant and curved.

2. Choose two places, A and B, a fair distance apart on a topographical map. Measure (a) the true bearing of A from B, (b) the true bearing of B from A. Is the second bearing the reciprocal of the first ?

3. Join A and B, and measure the angles the line AB makes with the various meridians. Find the approximate rhumb-line track from A to B. What is the rhumb-line track from B to A ? Are the rhumb tracks A to B and B to A reciprocal tracks ?

4.* Would a small triangle on the Earth's surface be represented by a similar triangle on a topographical map ? Give reasons.

5. Measure distances between various places on a topographical map.

6. Learn the symbols for the following : Land aerodrome, Landing ground, Air navigation light, Marine light, Light vessel, Overhead power cable, Explosives area.

7. What is the Representative Fraction of a map on a scale of 1 inch to 4 miles ?

8. How many miles to the inch are there in a map whose R.F. is 1/250,000 ? (Compare your answer with that of Question 7.) Answer to three significant figures.

9. Express the scale of a " half million map " in miles to the inch. Give answer to three significant figures.

CHAPTER IV

MERCATOR CHARTS

Why used by Navigators

WE have seen that navigators, whether by sea or air, find it most convenient to guide their craft along rhumb lines. Since the path of a craft is usually a rhumb line, it is an advantage for a navigator to use a map on which rhumb lines are represented by straight lines.

A Mercator Chart * is so constructed that *any straight line represents a rhumb line.* In order, therefore, to draw on his Mercator chart the rhumb-line path between any two places the navigator simply joins the places by a straight line. But he wants the track-angle, and indeed all angles, to be correctly represented on the chart. The second property of the Mercator chart is that *angles on the Earth's surface are represented by equal angles on the chart.*

From the two properties stated in italics in the last paragraph we can construct the graticule as follows :

(i) Meridians are rhumb lines and must therefore be represented by straight lines on the chart.

(ii) The Equator is a rhumb line cutting all the meridians at right angles. Hence on the chart the Equator will be a straight line cutting all the meridians at right angles. It follows that the meridians must be

---

* It is usual to speak of a Mercator *Chart* and of a Topographical *Map.* But there is no agreed difference between a chart and a map. Usually when a map shows more sea than land the map is called a chart. On the other hand, a topographical map may be drawn on Mercator's graticule, while sometimes a map which contains more sea than land is called a map rather than a chart.

a set of parallel straight lines, since they are all perpendicular to the Equator.

(iii) Parallels of latitude are also rhumb lines which, on the Earth's surface, cut all the meridians at right angles. Hence on the chart the parallels will be a set of parallel straight lines perpendicular to the meridians.

Distance between Parallels

Suppose Fig. 23 (i) represents a globe, and Fig. 23 (ii) part of a Mercator chart in which the Equator is the same length
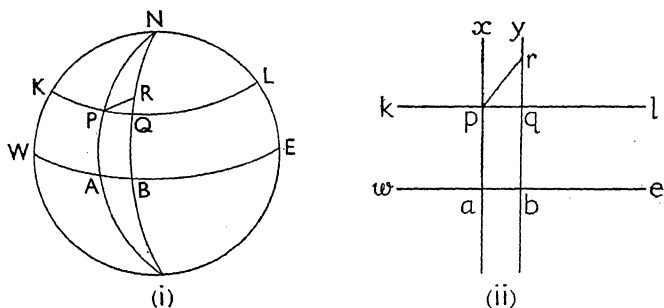
Fig. 23

as on the globe. Then, if the two meridians shown in Fig. 23 (ii) correspond to the two meridians in Fig. 23 (i), the length *ab* on the chart will be equal to the length AB on the globe.

Now suppose the globe to be covered with rubber sheeting, on which the meridians and parallels are drawn. To get the Mercator chart we take the rubber off the globe and stretch it east and west to make the *converging* meridians APN, BQN of the globe into the *parallel straight lines apx*, *bqy* of the chart. Clearly the farther a parallel such as KL is from the equator the smaller will be PQ, and therefore the greater the East-West stretch we shall have to apply.

Now if this East-West stretch were the only stretch applied we should get incorrect representation of *angles* on the chart. For, in that case, in a little triangle such as PQR, PQ would be stretched to *pq* while QR would not be altered in length. The angle *qpr* would then be smaller than the angle QPR.

To avoid this we now apply a North-South stretch to the rubber, stretching QR in the same ratio as we have stretched PQ. The farther the parallel is from the Equator the greater the East-West, and therefore the greater the North-South, stretch. This means that successive parallels, such as 10° N., 20° N., 30° N., etc., or 50° 01′ N., 50° 02′ N., 50° 03′ N., etc., will get farther and farther apart as we move North or South from the Equator (see Fig. 24).
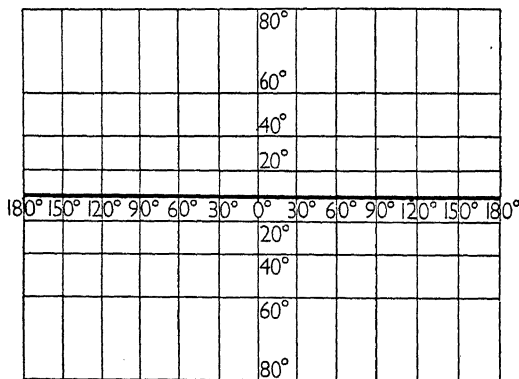
FIG. 24

Latitude and Longitude (see Chart A)

Example : To read off the latitude of LIZARD HEAD, either :

(i) lay the parallel rulers East-West passing through LIZARD, and read off the latitude as 49° 58′ N. on the latitude scale on the border, or

(ii) use dividers to find how many minutes LIZARD is north of the marked parallel (49° 50′ N.) South of it.

To read off the longitude of LIZARD either (*a*) set the parallel rulers North-South passing through LIZARD, and read off the longitude on the scale along the top or bottom of the chart, or (*b*) measure with dividers the number of minutes LIZARD is west of the nearest marked meridian. The longitude will be found to be 5° 13′ W.

The same methods may be used to mark on the chart a point of which the latitude and longitude are given.

Measurement of Distance

By "distance" in navigation we always mean *rhumb-line* distance. A distance measured along a great circle must be described as "great-circle distance."

The length corresponding to a degree of longitude decreases, on the Earth's surface, from 1 nautical mile at the equator to zero at either pole. Hence there is no simple relation on a Mercator chart between the length of minutes of longitude and distance in nautical miles.

At all parts of the Earth's surface, however, the length of a minute of *latitude* is 1 nautical mile.* Thus, on a Mercator chart a minute of latitude represents 1 nautical mile at any particular latitude.

In measuring distances (in any direction) in nautical miles on a Mercator chart *the scale of latitude must be used*, one minute of latitude representing 1 nautical mile.

As we have seen, the length of a minute of latitude on the chart increases as we go North or South from the equator. Hence the following method must be used in measuring distances.

----

* That is, assuming the Earth to be a perfect sphere. Owing to the flattening of the Earth at the poles the length of a minute of latitude changes slightly as we go from equator to poles. The average length is about 6,080 feet, and a nautical mile is taken to be of that length.

(i) To measure in nautical miles the length of a line AB on the chart (Fig. 25) :
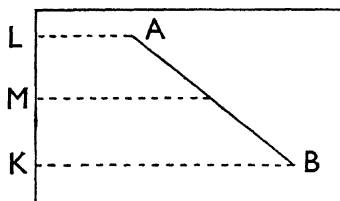
Fig. 25

(a) Find by eye the point (M) on the latitude scale approximately half-way between the latitude of A and that of B.

(b) If the dividers can be opened to length AB, open them, then place them on the latitude scale so that M is about half-way between the points. Then read off the distance in nautical miles.

(c) If AB is too long for the dividers open the latter to some convenient distance against the latitude scale, such as 25 nautical miles on each side of M. Step along AB, so finding how many steps of 50 n.m. there are. The part of AB left over (if any) after the stepping can be measured as in (b), using the scale about M as mid-point.

(d) If AB is very long, say 300 miles or more, it should be divided into two or three sections ; then find the mid-latitude of each section and measure each section as described in (c) above.

To lay off (*i.e.* draw) a distance, AB, say 250 n.m. long, in a direction, 140° say, from A (Fig. 25), judge roughly where B will be and so get the rough mid-latitude, M. Then set your dividers to a convenient length about M as mid-point, and step along the line of bearing.

(ii) Where a scale of Statute Miles is provided (as in Chart A), you must remember that such a scale increases as you go from the Equator, just as the latitude scale increases. In measuring or laying off distances in statute miles you will therefore use the methods described above, substituting the Statute Mile scale for the Latitude scale.

EXERCISE IV A

See Note on page xi.

1. Compare the length in cm. and mm. of the ten-minute interval of latitude from 48° N. to 48° 10′ N. with that from 51° 20′ N. to 51° 30′ N. [*AM*]

2.* Measure as accurately as you can in inches and decimals of an inch the length of the latitude scale from 49° 35′ N. to 50° 25′ N. Then, taking a nautical mile to be 6,080 feet, calculate the R.F. of the chart at latitude 50° N. [*AM*]

3. Find the latitude and longitude of : LIZARD HEAD, HART-LAND POINT, OKEHAMPTON, MAYENNE, MORLAIX. [*A*]

4. On your chart mark the points of which the latitudes and longitudes are as follows : (*a*) 48° 30′ N., 01° 40′ W. ; (*b*) 49° 55′ N., 03° 07′ W. ; (*c*) 51° 16′ N., 02° 27′ W. [*A*]

5. Find the latitude and longitude of : BRADFORD, EXETER, BEACHY HEAD, ESSEN, UTRECHT. [*M*]

6. On your chart mark the points of which the latitudes and longitudes are as follows : (*a*) 53° 20′ N., 02° 40′ W. ; (*b*) 53° 20′ N., 02° 40′ E. ; (*c*) 50° 33′ N., 04° 38′ E. ; (*d*) 53° 16′ N., 09° 27′ E. [*M*]

7. Find the distance in nautical miles from (*a*) START POINT to BILL OF PORTLAND ; (*b*) HESTON to SWINDON ; (*c*) BREST to LIZARD HEAD ; (*d*) RENNES to HESTON. [*A*]

8. Find the distance in nautical miles from (*a*) OXFORD to CAMBRIDGE ; (*b*) LEICESTER to EASTBOURNE ; (*c*) HESTON to BRUSSELS ; (*d*) DOVER to SAARBRUCKEN.   [*M*]

9. Find the distance in statute miles from (*a*) PORTLAND to CAP DE LA HAGUE ; (*b*) BEACHY HEAD to CAEN ; (*c*) RENNES to HESTON.   [*AM*]

10. Using the ratio 1 nautical mile/1 statute mile = 76/66, calculate from your answer to Question 9 (*c*) the distance from RENNES to HESTON in nautical miles.   Compare your answer with that to Question 7 (*d*).

Bearings

The rhumb-line bearing of one place from another on a Mercator chart is given by the angle at which the straight line joining the places cuts the meridians.   Thus (see Chart A) to find the rhumb-line bearing of PORTLAND from I. DE BAS join the points by a straight line and measure the angle at which this cuts any meridian (*e.g.* the meridian 3° W.).   This angle will be found to be 30°.   Thus the rhumb-line bearing of PORTLAND from I. DE BAS is 030°, while that of I. DE BAS from PORTLAND is 210°.

For short distances the rhumb-line bearing may be regarded as the same as the True (great-circle) bearing.   In none of the exercises of this book is it necessary to draw any distinction between the two kinds of bearing.

Bearings may be measured or laid off by any one of the following methods :

(i) Douglas Protractor.   This is a celluloid square, either 5 in. or 10 in. side, graduated along the edges from 0° to 360°, both clockwise and anti-clockwise. It is also divided into smaller squares by lines parallel to the edges to enable the instrument to be aligned with a track-line or a meridian and for other purposes. It is a most ingenious instrument, and by far the best kind of protractor for the navigator.   Full par-

ticulars of the modes of using it are supplied with the instrument.

(ii) Compass Rose. Place your parallel rulers along the line of bearing, then move the rulers, preserving their direction, until one of their edges passes through the centre of the compass rose on the chart. The bearing can then be read off on the rose.

(iii) Protracted Parallel Rulers. Set the rulers along the line of bearing. Then, preserving the direction, move the rulers until the mid-point of the base (usually marked S) is on any meridian. Close the rulers in this position when the acute angle between the bearing line and the meridians can be read off where the meridian cuts the protracted edge of the rulers.

EXERCISE IV B

1. Find the true bearing of (a) BRIGHTON from CHERBOURG ; (b) ALDERNEY LT. from START POINT ; (c) SALISBURY from CROYDON ; (d) SWINDON from CAEN. [A]

2. Find the true bearing of (a) IPSWICH from HESTON ; (b) AMIENS from EASTBOURNE ; (c) PORTLAND from CAMBRIDGE ; (d) NORWICH from AACHEN. [M]

3. Starting from EXETER an aircraft flies for 100 n.m. on track 080°. Find the latitude and longitude at the end of the run. [AM]

4. An aircraft leaves HESTON at 2100 hours * and makes good the following tracks :

Until 2130 hrs., 102° ; then until 2215 hrs., 075°. If the speed of the aircraft over the ground was 150 knots all the time, find the latitude and longitude at 2215 hrs. [M]

---

* A 24-hour system of stating times, starting from midnight, is used in navigation. Thus 2100 hours = 9 p.m., and 2215 hours = 10.15 p.m.

5. Leaving CROYDON at 0815 hrs. an aircraft flies on track 235° for 30 min., then on a track 280° for 20 min. If the speed over the ground was 150 knots all the time, find the latitude and longitude at 0905 hrs.   [AM]

* Great-Circle Track on Mercator Chart

To plot a great-circle track between two places, P and Q, on a Mercator chart we could first draw the great-circle track

(i)   (ii)
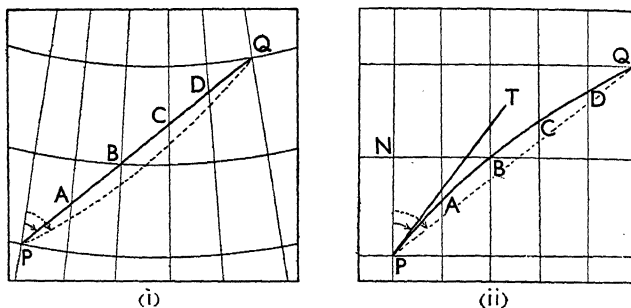
FIG. 26

on a topographical map, i.e. the straight line PQ in Fig. 26 (i). Read off the latitudes and longitudes of the points A, B, C, etc., where this track cuts the meridians on the topographical map. Then plot these latitudes and longitudes on the Mercator chart, Fig. 26 (ii). On the Mercator chart the great circle will be curved, convex towards the nearer pole.

The true bearing of Q from P in Fig. 26 (ii) is the angle NPT between the meridian at P and the tangent, PT, to the great-circle track at P. The rhumb-line bearing is the angle NPQ. The difference between the two bearings is called the *Conversion Angle*.

Conversion angles are of importance only when we wish to plot the great-circle bearing of one place from another on a Mercator chart when the two places are a considerable distance apart. This may happen, for example, when the (true) bearing of a distant wireless transmission station is

observed from the direction in which the wireless waves are received. In such a case we can avoid the troublesome process of drawing the whole great-circle track along which the wireless waves had travelled by calculating the conversion angle. This is approximately ($\frac{1}{2}$ Ch. Long. P to Q) × sin mean Lat. P and Q. Having calculated this angle we have only to apply it to the rhumb-line bearing to get the great-circle bearing at P. (See Chapter XI).

* *Meridional Parts*

The distance of any parallel of latitude from the Equator on a Mercator chart, *measured in minutes of longitude,* is called the " Meridional Parts " (Mer. Parts) for that latitude. Meridional parts are to be found in books of Nautical Tables, such as Inman's or Norrie's.

Meridional parts provide the best method of calculating the rhumb-line bearing of one place from another, a calculation which has to be performed if the places are too far apart to be shown on the same chart.
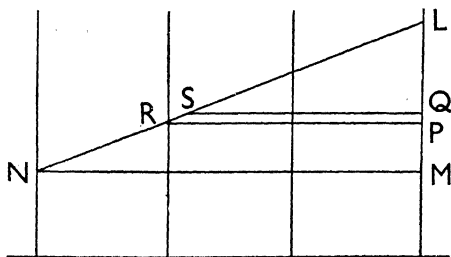
FIG. 27

Example. Find the rhumb-line bearing and distance from NEW YORK to LIVERPOOL.

In Fig. 27, N is NEW YORK and L is LIVERPOOL on a Mercator chart. EF is the Equator. We have to calculate angle MLN and the length LN.

We find the Ch. Long. NEW YORK to LIVERPOOL, express-ing it in minutes. That gives the length NM.

Now, in minutes of longitude,

$$EN = \text{Mer. Parts lat. NEW YORK}$$
$$FL = \text{Mer. Parts lat. LIVERPOOL}$$

Therefore,

$$ML = FL - EN = \text{Diff. Mer. Parts.}$$

We can now find the angle MLN from the formula

$$\tan MLN = \frac{NM}{ML}$$

The distance can be found from the fact that to every minute of latitude, such as PQ, there corresponds a distance RS which = PQ × sec MLN. Hence the whole distance NL = Ch. Lat. × sec MLN.

The work may be set out as follows :

NEW YORK	lat. 40° 43′ N.	Mer. Pts. 2,679	long.	74° 01′ W.
LIVERPOOL	lat. 53° 25′ N.	Mer. Pts. 3,805	long.	02° 58′ W.
	Ch. lat. 12° 42′ N.	Diffce. 1,126 N.	Ch. long.	71° 03′ E.
	= 762′ N.			= 4263′ E.

$$\tan MLN = \frac{\text{Ch. Long.}}{\text{Diffce. Mer. Pts.}} = \frac{4263}{1126} = 3 \cdot 786.$$

From table of tangents $\tan^{-1} 3 \cdot 786 = 75° 12′.$
Hence rhumb-line track $= 75° 12′$
                                                    or 075°.

Distance = Ch. Lat. × sec MLN
        = 762′ × sec 75° 12′
        = 2983′

The *great-circle* distance is 2,874′, that is, 109 n.m. less than the rhumb-line distance.

EXERCISE IV C (Revision)

1. Define : Great Circle, Small Circle, Earth's axis, South Pole, Equator, Meridian, Parallel.

2. Define : Latitude, Longitude.

3. Find the Ch. Lat. and Ch. Long. from (*a*) HESTON to BREST ; (*b*) TROUVILLE to OKEHAMPTON ; (*c*) CROYDON to WOLF LT. (*A*)

4. Find the Ch. Lat. and Ch. Long. from (*a*) IPSWICH to LEEDS ; (*b*) HESTON to REIMS ; (*c*) CROYDON to HELIGO-LAND. [*M*]

5. Find the true bearing of (*a*) C. DE LA HAGUE from BILL OF PORTLAND ; (*b*) EDDYSTONE from GRANVILLE ; (*c*) EXETER from READING. [*A*]

6. Find the true bearing of (*a*) NORWICH from CAMBRIDGE ; (*b*) LILLE from LEICESTER ; (*c*) DOVER from NANCY. [*M*]

7. How many miles to 1 inch are there on a map of R.F. 1/1,000,000 ? Answer to three significant figures.

8. On a sketch of a Topographical Map graticule, mark two places, A and B. Show the great circle and the rhumb line joining A and B. Then on a sketch of a Mercator graticule of the same region mark A and B, and show the great circle and rhumb line joining the two places.

CHAPTER V

WIND

Effect of Wind on an Aircraft in Flight

IF an aircraft is moving in any direction, its speed over the ground will be the same as its speed through the air provided the air is still—that is, if there is no wind. Thus if the direction in which the aircraft is heading (the " Course ") is 040°, and the speed through the air (the " Air-Speed ") is 150 m.p.h., the aircraft will move *over the ground* at 150 m.p.h. in direction 040°. We should say that the Ground-Speed was 150 m.p.h. and the Track 040°.
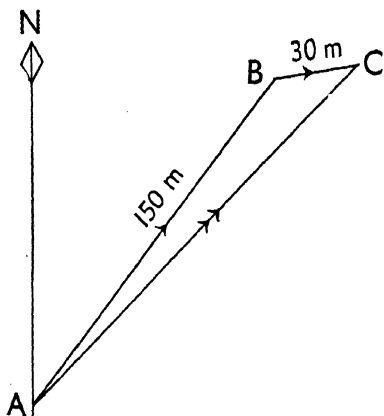
If there is a tail wind (*i.e.* one blowing in the direction of the course) of, say, 30 m.p.h., the aircraft would not only move *through* the air at 150 m.p.h., but *with* the air at 30 m.p.h. in the same direction. Then the ground-speed would be 180 m.p.h. and the track 040°.

If nosing directly into a head wind (*i.e.* one blowing in the opposite direction to the course) of 30 m.p.h. the aircraft would have a ground-speed of 120 m.p.h.

If there were no wind the aircraft starting at A (Fig. 28) would arrive at B, 150 m. in direction 040° from A, after 1 hr.

FIG. 28

Now suppose a wind of 30 m.p.h. blows from direction 260°. During the hour this current of air will carry the aircraft 30 m. in the direction 080°, which is opposite to ·260°. So, instead of arriving at B, the aircraft will arrive at C after 1 hr. Actually the aircraft has moved over the ground along AC. The length of AC in miles will give the ground-speed in m.p.h., and the direction of AC will be the track.

Triangle of Velocities

A velocity is a speed in a definite direction. Thus, 150 m.p.h. is a speed while 150 m.p.h. in direction 040° is a velocity.

It is easy to see that the Ground Velocity (*i.e.* Ground-Speed in direction of Track) is the result of two velocities :

(i) Air-speed *through* the air in direction of the course.
(ii) Wind-speed *with* the air in direction towards which the wind is blowing.

We say that the Ground Velocity is the *resultant* or "Vector Sum" of the "Component Velocities" Air Velocity and Wind Velocity.

To take a fresh example, suppose an aircraft has air speed 120 m.p.h., course 230°, and that there is a wind of 40 m.p.h. blowing from 340°. From what has been said above you will understand that we can find the ground-speed and track as follows (Fig. 29) :

Choose any scale of speed. A convenient scale for most problems of this kind is 1 cm.= 10 m.p.h.

Fig. 29

On this scale draw AB 12 cm. long to represent 120
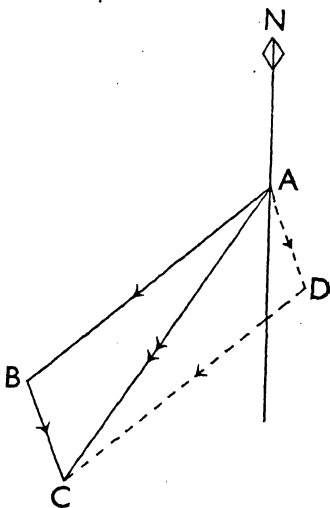
m.p.h. in direction 230° with reference to the line AN which represents the meridian.

From B draw BC 4 cm. long to represent the wind of 40 m.p.h. from 340°.

Join AC. The length of AC in mm. is the ground speed in m.p.h., while the direction of AC is the track. In this particular case the ground-speed is found to be 139 m.p.h. and the track 214°.

The triangle ABC is called a *triangle of velocities.*

Note that we should have got the same result if we had first drawn the Wind vector, AD, and then the Air Velocity vector, DC. In some navigational problems it is better to use triangle ABC, in others triangle ADC.

Note : Whenever drawing a triangle of velocities, note carefully the following points :

 (i) Before drawing the triangle, a speed scale must be chosen. 1 cm. = 10 m.p.h. or 10 knots is often convenient. On a chart you may use the longitude scale to represent speeds, taking 1′ to represent 1 m.p.h. or 1 knot. You must *not* use the latitude scale, since that scale is not uniform.

 (ii) Draw a line to represent the true meridian, marking its North end. If you draw the triangle on a chart you can, of course, use one of the meridians marked on the chart.

 (iii) The *directions* (Course, Wind, Track) must be marked by arrows, *two* arrows on track.

 (iv) *The Course-arrow must point in the same direction round the triangle as the Wind-arrow points, but Track-arrow must point the opposite way round.*

 (v) The term " Wind Direction " means the direction *from* which the wind blows. In the triangle of velocities, of course, the wind-arrow shows the direction *towards* which the wind blows.

Wind velocity is usually written thus, W/V 157°/25 m.p.h., which means a wind of 25 m.p.h. blowing from direction 157°. Wind directions are always True directions, so that it is not necessary to write T after them.

EXERCISE V A

1. Copy and complete the following :—

	T.A.S.	Co.	W/D	W/S	Tr.	G/S
(a)	120 m.p.h.	062° T	015°	30 m.p.h.		
(b)	220 m.p.h.	148° T	205°	35 m.p.h.		
(c)	160 k.	241° T	310°	25 k.		
(d)	115 k.	297° T	175°	20 k.		

2. An aircraft starts from READING on a course 250° T, with T.A.S. 160 k. and W/V 20 k. from 350°. Draw the triangle of velocities to find the track and ground-speed. Find the latitude and longitude after 1 hr.   [A]

3. Starting from GREAT YARMOUTH an aircraft flies on a course 133° T with a T.A.S. 175 k. Wind velocity is 27 k. from 015°. Draw the triangle of velocities to find the track and ground-speed. Find the latitude and longitude after 1 hr.   [M]

4. W/V is 18 k. from 140°. T.A.S. 125 k. Co. 140° T. What is the ground-speed ?

5. W/V is 21 m.p.h. from 340°. T.A.S. 185 m.p.h. Co. 160° T. What is the ground-speed ?

Drift

Suppose an aircraft to be flying on Co. 050° T at T.A.S. 120 m.p.h. There is a W/V of 30 m.p.h. from 270°. By the triangle of velocities (Fig. 30) we find the track to be 058° T.
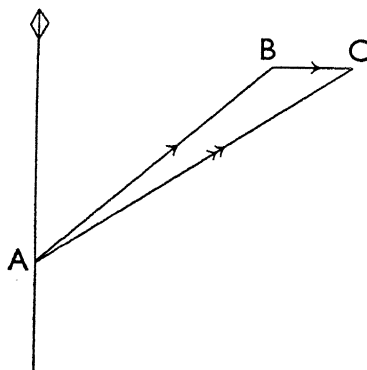
FIG. 30

In Fig. 31 we see the aircraft heading in direction OP (050°), but moving over the ground in direction RT (058°). The wind drifts the aircraft off its course on to the track. The angle between the Course and the Track is called DRIFT. In this case the Drift is 8°.
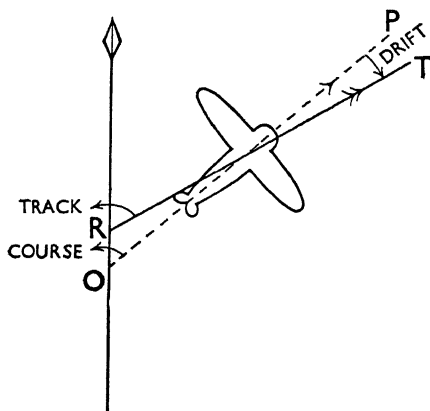

FIG. 31

If, as in the present case, the track is to the right of the course the drift is STARBOARD. We say the drift is 8° S. If the track is to the left of the course the drift is PORT.

Note : (i) Wind always blows " from Course to Track."
(ii) Course + Starboard Drift = Track
Course — Port Drift   = Track.

Finding the Wind Velocity

The case of the triangle of velocities described above rarely arises in practice. The two cases of the triangle considered in the present and next paragraphs are normally used several times during a flight of any considerable length.

While the navigator receives before setting out on his flight forecasts of the wind velocity from the meteorologist the forecasts may not prove to be accurate, and the wind may change in force and direction during the flight. Whenever, therefore, he has an opportunity, the navigator checks the wind velocity.

There are numerous ways of measuring the wind velocity, but one of the simplest and most commonly used consists in measuring the track and ground-speed and comparing these with the course and air-speed. By noting the times at which we fly over two known points we can calculate the ground speed, while the join of the points on the map will give us the track. The compass tells us the course, and the air-speed indicator gives the air speed.

Example : At 0900 hours a navigator pinpoints BARNSTAPLE. The aircraft flies on a course 100° T at T.A.S. 150 k. At 0930 DORCHESTER is pinpointed. Find the W/V.

By joining BARNSTAPLE to DORCHESTER on the chart (Chart A) we measure the track between those places as 110° T.

The distance between the places is found to be 65 n.m. Hence, as the run between the places took ½ hour the ground speed is 130 k.

Draw AB 15 cm. long in direction 100° to represent the air-speed and course (Fig. 32).   Mark the arrow.

Draw AC 13 cm. long in direction 110° to represent ground-speed and track.   Mark the double arrow.
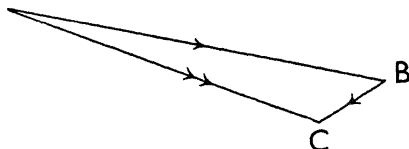
FIG. 32

Join BC and mark the arrow pointing round the triangle in the same (clockwise) sense as the air-velocity arrow.

Then BC represents the wind velocity.   It is found to be 3·2 cm. long, representing a wind-speed of 32 k.   By measuring the direction of BC we find that the wind is blowing from 056°.   The W/V is 056°/32 k.

EXERCISE V B

1. Copy and complete the following :

	T.A.S.	Co.	G/S	Tr.	W/S	W/D
(a)	138 k.	310° T	126 k.	298°		
(b)	175 m.p.h.	193° T	178 m.p.h.	206°		
(c)	110 k.	125° T	118 k.	135°		
(d)	182 m.p.h.	027° T	197 m.p.h.	030°		

2. Flying on Co. 243° T at T.A.S. 135 k. an aircraft passes over CROYDON at 1420 hours and SALISBURY at 1450 hours. Find the G/S, Tr., and W/V.   [A]

3. Flying on Co. 240° T at T.A.S. 150 k. an aircraft passes over LINCOLN at 1650 hours and SHREWSBURY at 1722 hours. Find the G/S, Tr., and W/V.   [M]

4. Co. 147° C. T.A.S. 170 k. Var. for 1942. Dev. as per curve provided. At 1125 hours the navigator pinpoints BRIDGEWATER, and at 1136 hours DORCHESTER. Find True Co., Tr., G/S, Drift, and W/V.   [A]

Course to steer to make good a given Track

It is desired to fly from HESTON to EXETER. By joining these places on the chart (Chart A) we find that the track from HESTON to EXETER is 249°. Given that the T.A.S. is 150 k. and that there is a 30 k. wind blowing from 320° what course should the pilot steer ?

Method (see Fig. 33) :

    (i) Draw AX of sufficient length running in the direction (249°) of the track from a point A on the meridian.
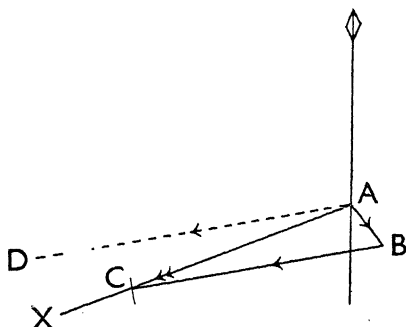
FIG. 33

    (ii) Draw the wind vector, AB, *down wind from A.*

(iii) Open compasses or dividers to the air-speed (150 k.) on the speed scale, and with B as centre strike an arc at C across AX.

The direction of BC gives the (True) course required (260° T).

The length AC gives the ground-speed (137 k.).

In solving this important problem of finding course to make good a given track always *use the method given above.*

The student may have a little difficulty in deciding whether the drift is port or starboard in such a figure as Fig. 33. There are two ways :

(i) Think of the course as set off *from A* (AD). The drift is then seen to be port.

(ii) Consider the measurements. Track = 249°, Course = 260°. Track is less than course, so that drift is port.

EXERCISE V C

1. Copy and complete the following :

Tr.	T.S.A.	W/D	W/S	Co. (T)	G/S
(a) 076°	120 k.	295°	21 k.		
(b) 310°	172 m.p.h.	015°	18 m.p.h.		
(c) 200°	140 k.	253°	32 k.		
(d) 157°	160 m.p.h.	260°	25 m.ph.		

2. Find the true course, drift, ground-speed, and times taken to cover the distances stated in the following :

	Tr.	Distance	W/D	W/S	T.A.S.
(a)	158°	238 n.m.	080°	28 k.	170 k.
(b)	295°	112 n.m.	355°	32 k.	140 k.

3. Using variation for 1942 and deviation curve provided, find the compass course to steer and the time taken between the following places : [*A*]

    (*a*) FLERS to BARNSTAPLE.   T.A.S., 165 k. W/V 048°/28 k.

    (*b*) I. DE BAS to NEWHAVEN.   T.A.S., 138 k. W/V 110°/20 k.

    (*c*) BRIDGEWATER to TROUVILLE. T.A.S., 157 k. W/V 075°/29 k.

4. Using variation for 1940 and deviation table provided, find the compass course to steer and the time taken between the following places : [*M*]

    (*a*) HESTON to BRUSSELS.   T.A.S., 160 k. W/V 237°/32 k.

    (*b*) IPSWICH to GRÖNINGEN.   T.A.S., 152 k. W/V 163°/18 k.

    (*c*) EMDEN to CROYDON.   T.A.S., 170 k. W/V 010°/25 k.

5. At 1100 hrs. an aircraft over WINCHESTER sets course for BREST. T.A.S. 168 k. W/V 335°/22 k. Find compass course to steer, G/S, and E.T.A. [*A*]

Further Methods of Wind Finding

Although before setting out on a flight the air navigator is given forecasts of wind-velocity by the meteorologist, the forecasts may not prove to be correct, and the wind may change. It is therefore necessary to be constantly checking up the wind. The most straightforward and commonly used method is that of finding ground-speed and track as described on page 65. But there are numerous other methods of which two of the simpler are described below.

(i) By Air Plot. This depends upon fixing the position of the aircraft at two times, but, unlike the method given on page 65, does not involve calculation of ground-speed or drawing of a triangle of velocities.

An **aircraft** leaves a known place P (Fig. 34) on (say)

course 060° T at T.A.S. 120 m.p.h.   After a time (say
20 minutes) the aircraft is found to be over a place R.   On
the chart draw PQ in the direction of the true course, 40 m.
long, being the distance moved through the air in 20 min.
Q is where the aircraft would have been, *if there were no
wind,* at the time when actually it is over R.   Q is called
the " Air Position " at that time.
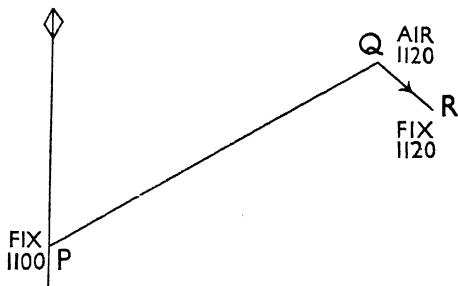
FIG. 34

QR is the wind's effect for 20 min.   If we find QR = 8 m.
the wind-speed will be 8 × 3 = 24 m.p.h.   The direction
of QR gives the wind direction.

(ii) By Drift.   There are various ways in which drift can
be measured.   One way is to take a bearing (called a " Back
Bearing ") of an object over which the aircraft has passed.
Suppose such an object bears 220° T.   Then provided the
aircraft does not alter course and the wind does not change,
the object will continue to bear 220° T, and the track will
be the reciprocal (040° T) of this bearing.   Comparison of
this track with the true course gives the drift.   If drift on
two or more courses is measured, the wind velocity can be
found as follows :

Example : On course 050° T drift is observed to be 8° S.
                On course 160° T drift is observed to be 10° P.
                        T.A.S. = 140 k.

Draw (Fig. 35) AO to represent the T.A.S. 140 k. on the first course, 050°.

Then, using the 8° S drift, draw the first track, AX.

Draw BO to represent the T.A.S. on the second course, 160°.

Then from the 10° P drift, draw the second track BY.

If AX and BY intersect at W, OW is the wind-vector. Its length, according to the scale of speeds adopted, gives the W/S, and its direction gives the W/D.

For, clearly, the vector OW added to vector AO gives the
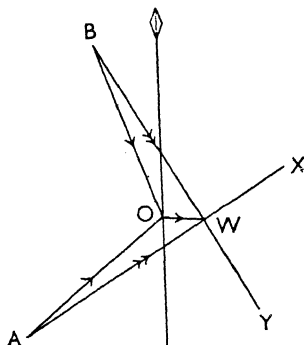
FIG. 35   FIG.
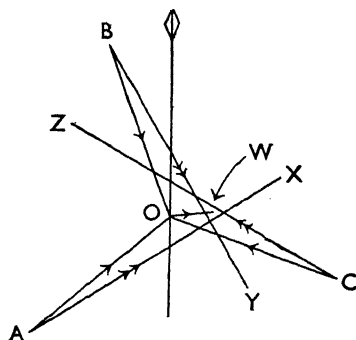
correct first track AX, while OW added to vector BO gives correct second track BY.

Usually a second alteration of course is made and the drift observed on the third course. If all three observations of drift were exact, the three track-lines would pass through one wind point W. Usually the track-lines form a little triangle (called a " Cocked Hat "), and W is taken to be the centre of the triangle.

Suppose, in addition to the two observations illustrated in Fig. 35, an observation of drift 9° S was made on course 290° T. The wind would then be found as shown in Fig. 36.

EXERCISE V D

1. At 1150 hrs. an aircraft passes over BILL OF PORTLAND on a course 250° T.   T.A.S. 150 k.   At 1205 the navigator pinpoints BERRY HEAD.   Find the W/V.   [A]

2. 1755 hrs., aircraft leaves NEWHAVEN on 280° T, at T.A.S. 160 k.   At 1806 hrs. a/c to 225° T.   At 1818 hrs. ST. CATHERINE POINT is pinpointed.   Find the W/V.   [A]

3. An aircraft flies on two courses, and drift is observed as follows :

> On course 155° T, drift   9° S.
> On course 282° T, drift 10° P.

If the T.A.S. is 165 m.p.h., find the W/V.

4. If T.A.S. is 180 m.p.h., find the W/V from the following observations of drift :

> Course 075° T, drift   7° P.
> Course 350° T, drift   9° S.
> Course 285° T, drift 10° S.

CHAPTER VI

FIXING AND REPORTING POSITION

Fixes

The " Dead Reckoning " position of an aircraft is the position estimated from the courses flown, air-speed, and most probable wind velocity. The latter is very liable to error, so the navigator checks his position by observation of landmarks, or stars, or wireless beams, when opportunity occurs. The ground-position of an aircraft obtained from such observations is called a FIX.

Pinpointing

A ground feature immediately below the aircraft is identified. The position is recorded by the name of the feature against the time. *E.g.*

<blockquote>1115 hours.   SKERRIES LT.</blockquote>

Note : The feature must not be too large to define the position with adequate accuracy. Thus

<blockquote>1120 hours.   LONDON</blockquote>

would not serve.

Bearing and Distance

If the (horizontal) distance of an object can be ascertained (*e.g.* by rangefinder), and its bearing measured, a fix is obtained by laying off the distance along the reciprocal bearing from the object on the chart. Thus suppose (see Chart A) EDDYSTONE bears 048° T., 15 n.m. Then the aircraft is at a position 15 n.m. on bearing 228° T from EDDYSTONE. If you plot this position on the chart you will find it to be 50° 01′ N., 04° 34′ W.

Such a fix is recorded thus :

   0819 hours. 228° EDDYSTONE 15 n.m.

Alternatively we could record

   0819 hours. EDDYSTONE bore 048° T.

Position Lines

A position line (abbrv. P/L) is a line, obtained from observation of terrestrial or astronomical objects, somewhere on which the aircraft must lie at the time of the observation.

 (i) Ground feature P/L. A railway line, for instance, observed beneath the aircraft, is identified on the map, but the particular point on the railway where the aircraft is situated is not known. Then the railway line on the map is a position line.

 (ii) Compass bearing. The bearing of an object is taken with a compass. This is corrected for deviation (according to the *course of the aircraft*), and for variation. Then the reciprocal bearing is laid off on the chart from the object as described above. As only the bearing, not the distance, of the object is known we get a position line, but not a fix.
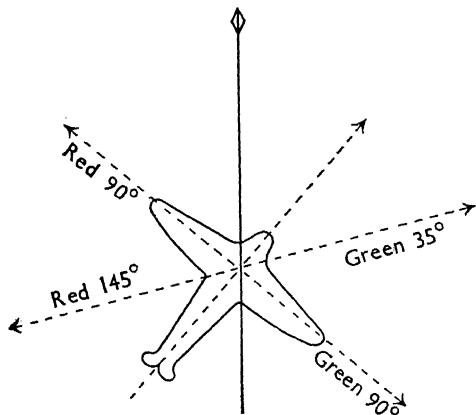

FIG. 37

(iii) Relative bearing. Bearings may be taken relative to the aircraft head (Fig. 37). They are measured in degrees 0° to 180° to Port (Red), or Starboard (Green).

Suppose an object is found to bear Green 35°. If the course of the aircraft is 040° T the bearing of the object is clearly 075° T.

We then draw the position line on the chart as described above.

(iv) Transit. If two objects are seen in "transit," that is, in line with the observer, the join of the objects produced gives a position line. The symbol for "in transit with" is ϕ. Thus the observation shown in Fig. 38 would be recorded thus :

2218 hours. CHURCH ϕ FLAGSTAFF

Position lines are indicated on the chart by arrows at the ends.
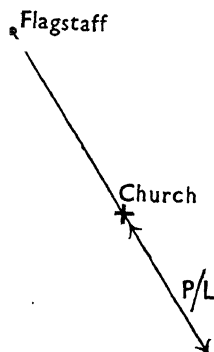
FIG. 38

Fix by Cross Bearings

If two position lines are obtained by observations *at the same time*,* the position of the aircraft at that time is where the lines intersect. When the position lines are lines of bearing, a position so obtained is called a Fix by CROSS BEARINGS.

Thus suppose (see Chart A) that a navigator observes that ST. CATHERINE PT. bears 055° T, while at the same time ANVIL PT. bears 330° T. He draws the first P/L running 235° (reciprocal of 055°) from ST. CATHERINE PT., and the second P/L running 150° from ANVIL PT. The fix so obtained is 50° 22′ N., 01° 46′ W.

* This is only practically possible when the bearing of at least one of the objects is changing *slowly.*

EXERCISE VI A

1. An object is observed to bear 127° by compass. Var. 11° W. Dev. as per curve. Co. of aircraft 324° C. Find the true bearing of the object.

2. START PT. bears 273° C. Co. of aircraft 220° C. Var. for 1942. Find the true bearing and draw the position line.

At the same time BERRY HD. bears 345° C. Draw the position line and find the fix.   [A]

3. BEACHY HD. bears 335° C. Co. of aircraft 270° C. Var. for 1940. Find the true bearing and draw the position line.

At the same time DUNGENESS bears 025° C. Draw the position line and find the fix.   [M]

4. NEEDLES φ ST. CATHERINE. Draw the position line.

At the same time ANVIL PT. bore 228° C. Co. of aircraft 255° C. Var. for 1942. Draw the second position line and find the fix.   [AM]

5. At 0835 hours PORTLAND bore 325° T and ANVIL bore 042° T. Find the fix. At the same time course is set for HESTON, T.A.S. 160 k. W.V 155°/28 k. Find the true course to steer, the distance to be covered, the ground speed, and the E.T.A.

6. Find the true bearings corresponding to each of the following relative bearings :

| Co. (T) of aircraft . | 052° | 215° | 137° | 342° |
| Relative bearing . | Green 25° | Red 95° | Red 45° | Green 110° |

7. SCARWEATHER bears Green 45°. Co. 265° T. Draw the position line.   [A]

8. HELIGOLAND LT. bears Red 90°. Co. of aircraft 257° T. Draw the position line.

Cocked Hat

If *three* simultaneous position lines were obtained they would all, if the observations were quite accurate, pass through the same point, namely, the position of the aircraft. Usually they form a small triangle, called a " Cocked Hat." The position is taken to be the centre of the cocked hat. Thus (Fig. 39) simultaneous bearings of the three points A, B, and C along a coastline give the cocked hat shown. The dot inside the triangle is taken to be the fix.
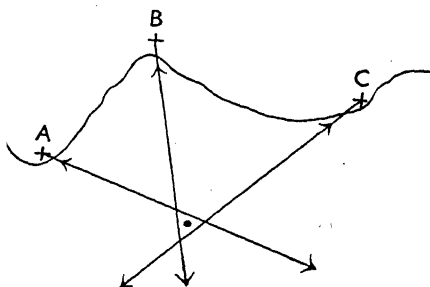

Fig. 39

Running Fix

Simultaneous position lines are often unobtainable. Position lines obtained from observations made at different times may be combined to provide a fix as follows :
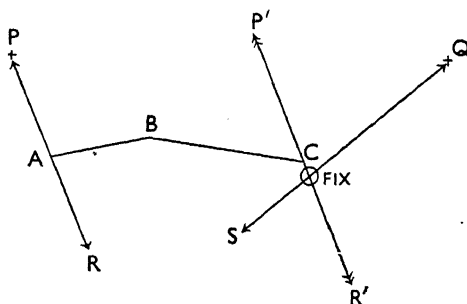
Fig. 40

Observation of the bearing of a point P at (say) 1150 hrs. (Fig. 40) gives a position line PR. This is then drawn on the chart.

The aircraft then continues on its course. Suppose during the next 10 min. the aircraft moves 10 m. on a track 080° T, then 12 m. on a track 115° T. From *any* point, A, on PR set off the aircraft's runs, AB, BC, and through C draw P'R' parallel to PR. Then at 1200 hrs. the aircraft is on P'R'. This line (*i.e.* the original position line PR moved parallel to itself through the ground distance travelled by the aircraft) is called a " Transferred Position Line." It is marked with double arrows.

At 1200 hrs. we take the bearing of a point Q. The intersection of the position line, QS, obtained from the 1200 hrs. bearing, with the transferred position line P'R' gives the fix at 1200 hrs.

A fix obtained by transferring a position line is called a Running Fix.
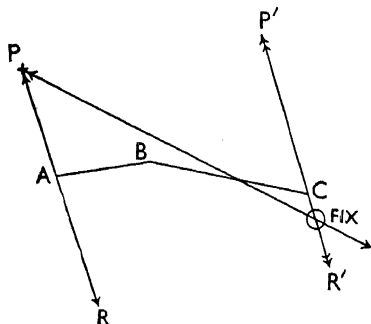
Fig. 41

Note that (Fig. 41), instead of bearings of two objects, P and Q, successive bearings of the *same* object (P) may be used in a Running Fix.

EXERCISE VI B

1. At 0830 hrs. St. Catherine Pt. bears 010° T. Aircraft moves on a track 266° T at ground-speed 120 k.

At 0845 hrs. Portland bears 300° T.

Find the fix at 0845 hrs. [*AM*]

2. At 1050 hrs. Hartland Pt. bears 100° T.

During the next 20 min. the aircraft makes good the following runs : 15 n.m. on Tr. 190° T ; 20 n.m. on Tr. 210° T.

At 1110 hrs. Trevose Hd. bears 045° T.

Find the fix at 1110 hrs. [*A*]

3. A ship is steaming 112° T at 30 k. At 1635 hrs. Portland bears 070° T. At 1655 hrs. Portland bears 350° T. Find the fix at 1655 hrs. [*AM*]

4. 1240 hrs. Co. 245° C. Var. for 1942. T.A.S. 180 k.

Lowestoft Lt. bears 340° C.

Southwold Lt. bears 255° C.

Find the fix at 1240 hrs.

S/c Heston. W/V 125°/30 k.

Find compass course to steer, ground-speed, distance, and E.T.A. [*M*]

Methods of Reporting Position

Non-secret Methods

(i) Pinpoint. This is a non-secret method.

(ii) Latitude and longitude. Also non-secret.

(iii) Bearing and distance. Non-secret. Note carefully the following :

(*a*) Bearing is always stated *before*, distance *after*, the name of the reference point. This can be remembered by noting that alphabetically B for bearing comes before D for distance.

(*b*) The bearing is the bearing of *the aircraft's position from the reference point.*

(*c*) The bearing is a *true* bearing.

(*d*) Unless the units of distance are understood by those to whom the report is made the units must be stated :

0819 hrs.   228° WOLF 15 st. m.

Secret Methods

A method of reporting position useful in wartime is that of *Lettered Co-ordinates.*
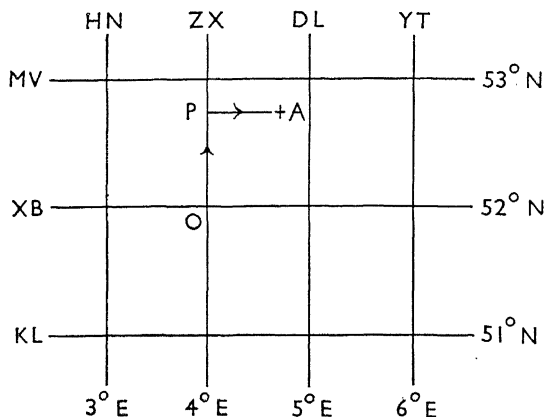
FIG. 42

(i) To each degree of latitude and longitude is assigned a pair of letters (Fig. 42).   The letters can be varied whenever necessary, secrecy being in that way maintained.

(ii) To report position of any point A, first name the reference point O, which is the *South-West corner of the latitude-longitude oblong in which* A *is situated.*   This is done by writing XBZX.

Note : *Latitude* letters *first, longitude* letters *second.*

(iii) Next write : Minutes of latitude A is North of O followed by   Minutes of longitude A is East of O.

Thus, if A is the point 52° 41′ N., 4° 50′ E., the complete description of the position is

XBZX 4150.

(iv) In West longitude the minutes of longitude are still reckoned *eastwards*. Thus if (Fig. 43) B is the point 51° 53′ N.,
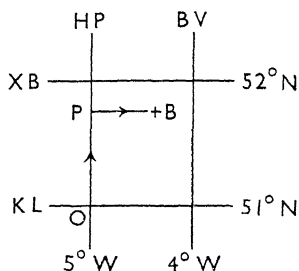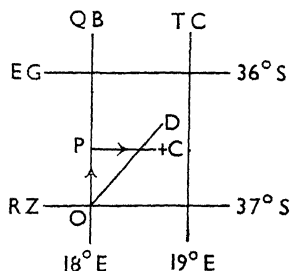
Fig. 43   Fig. 44

4° 22′ W., we calculate PB = 60′ — 22′ = 38′.   Hence B is the point

KLHP 5338.

(v) In South latitude the minutes of latitude are still reckoned *northwards*.

Thus, in Fig. 44, C, the point 36° 37′ S., 18° 49′ E. would be described as   RZQB 2349.

(vi) In Fig. 44, O itself would be reported as

RZQB 0000.

Royal Navy Method

The position is reported as a bearing and distance from a lettered co-ordinate reference point.

Thus, if in Fig. 44, OD = 41 n.m. and the bearing of D from O is 052° T, D's position would be reported by the Royal Navy method as

052 RZQB 41.

EXERCISE VI C

In this and subsequent exercises, where lettered co-ordinates are employed, the following references are to be used :

Lat. 48° N. . . . MJ	Long. 4° W. . . . HD	Long. 4° E. . . JU
49° N. . . . PH	3° W. . . . EA	5° E. . . AW
50° N. . . . BX	2° W. . . . ML.	6° E. . . DY
51° N. . . . MW	1° W. . . . CH	7° E. . . EX
52° N. . . . BV	0° . . . AB	8° E. . . KG
53° N. . . . MU	1° E. . . . BD	9° E. . . DQ
54° N. . . . CM	2° E. . . . DK	10° E. . CR
55° N. . . . QY	3° E. . . . GT	11° E. . ET

1. Express in lettered co-ordinates the positions :   [A]

(a) 49° 12′ N., 03° 32′ W. ; (b) EDDYSTONE ; (c) PORTLAND BILL.

2. Express each of the positions in the previous question by the R.N. method, using the S.W. corner of the graticule oblong as reference point.

3. Find the latitude and longitude of :   [M]

(a) 322 DUNKERQUE LT. 15 n.m. ; (b) 135 DUNGENESS 21 n.m. ;
(c) 074 FLAMBOROUGH 12 st.m. ; (d) 237 CAP DE LA HAGUE 14 st.m.

4. Express each of the positions in the previous question by :

(i) lettered co-ordinates ; (ii) R.N. method.

5. What is the bearing of C. GOOD HOPE from 247 C. GOOD HOPE 12 ?

6. Using the references given below, express in lettered co-ordinates the following positions :

(a) 01° 00′ N. 02° 00′ E. ;   (b) 01° 23′ N. 01° 48′ E. ;
(c) 01° 23′ N. 01° 48′ W. ;   (d) 01° 23′ S. 01° 48′ E. ;
(e) 01° 23′ S. 01° 48′ W. ;   (f) 02° 54′ N. 01° 00′ E. ;
(g) 01° 46′ S. 00° 00′.

Reference

Lat. 00° .	DG	Long. 00° .	AB
01° N.	BK	01° E.	BD
02° N.	NO	02° E.	DK
01° S.	LB	01° W.	LH
02° S.	AC	02° W.	ML

CHAPTER VII

PLOTTING

Knowledge needed in Plotting

WHEN planning a flight and, so far as possible, during the flight, the air navigator plots his track-lines and positions on a chart. He will also, when possible, keep an air plot— that is, a plot of courses and air-speeds, and he will frequently have to find courses to set, or wind velocity, by drawing triangles of velocity or using a navigational computer.

The student should now be able to carry out a variety of plotting exercises, since all the knowledge he needs he will now have if he has read this book and worked the exercises carefully up to this point. It may be useful to summarize here the knowledge required.

Apart from knowing the symbols used on maps and charts, the plotter must understand :

    (i) how to mark on the chart points whose positions are given by any of the various methods ;

    (ii) how to measure and lay off bearings and distances on charts.

He must know :

(iii) the various methods by which fixes may be obtained ;

(iv) the various applications of the triangle of velocities.

If the student feels doubtful about any of these points he will be wise to turn back to the part of the book dealing with his difficulty before proceeding further.

Kinds of Position

Note the following :

(i) Dead Reckoning position is the position found from True Course, Air-speed, and *the probable Wind Velocity.*

(ii) A Fix is the ground position of the aircraft determined by terrestrial, radio, or astronomical observations.

(iii) Air Position is the position calculated from courses followed and air speed only ; it would be the true position if there were no wind.*

As soon as a fix has been obtained, the D.R. position should be discarded, any subsequent plotting being carried on from the fix.

Points of Importance in Plotting .

(i) When drawing triangles of velocities :

(*a*) State the scale of speed employed.   You may use a mm. scale, or the longitude scale, for speeds, but you must NOT use the latitude scale.

(*b*) Mark arrows on all vectors.

(*c*) The triangles may be drawn on the chart but, at any rate for beginners, it is advisable to draw them away from the actual track-lines (otherwise confusion may arise between lines representing distances and lines representing speeds).

(ii) Use a *sharp* pencil, not too hard.   HB or B is suitable.

(iii) When drawing a line through a position on the chart, first place the pencil point on the position, then bring the straight edge up to the pencil.   This reduces inaccuracy due to the thickness of the pencil point.

(iv) Use instruments carefully :

(*a*) When using dividers see that the legs are opened as exactly as possible to the required distance.

* In sea navigation the position found from course steered and speed (corresponding to Air Position) is called Dead Reckoning position.   When allowance is made for currents (which correspond to wind) the position is called the Estimated Position.

(*b*) When using a protractor make sure that the centre is on the meridian and that the instrument is aligned with the meridian or (if the instrument is being used that way) with the line of bearing.

(*c*) Be careful to avoid slipping when using parallel rulers.

(v) A 2-foot celluloid ruler is very useful. If you have no long ruler and you wish to join two distant places on the chart, fold over the chart so that one of its edges passes through the two places.

(vi) Always write place names, on chart, in log, or in your calculations in BLOCK CAPITALS.

(vii) Do not make calculations on scraps of paper. It is important that all a navigator's notes and calculations should be preserved, and that they should be intelligible to any reader. Work neatly and systematically, setting out data and work in tabular form wherever possible.

(viii) When you find a Wind Velocity enter it in your notes or log in a " box " thus $\boxed{325°/16 \text{ k.}}$

(ix) <u>Underline</u> all E.T.A.'s. A new E.T.A. should be calculated whenever an alteration of course is made.

(x) Keep your chart clean by rubbing out your plots when you have finished with them.

(xi) Degrees of accuracy : Variations, Deviations, Courses, Tracks, and Bearings should be stated to the nearest degree. The accuracy with which you can measure or lay off distances will depend partly upon the scale of the chart. Never state distances to a closer " accuracy " than half a mile, and usually be content with the nearest mile. In practice you frequently do not know your position more accurately than within five miles.

(xii) Unless there is a statement to the contrary, all times in plotting exercises should be assumed to be Greenwich Mean Time (G.M.T.).

Example of a Plotting Exercise

The following plotting exercise should now be worked by the student on Chart A. It is given to illustrate a number of points and general procedure. The exercise also shows the manner in which most of the exercises following this chapter are set out. The student is advised to have a systematic way of setting out his work, and the scheme used in this question will often serve the purpose.

Example :

Hours

0800　HESTON. S/c OKEHAMPTON.. T.A.S. 160 k. W/V
　　　　310°/25 k.
　　　　Co. *259°* (T)　　*270°* (M)　　*265°* (C)　　Drift *7°* P
　　　　G/S *146* k.　Distance *141* n.m.　E.T.A. *0858*

0824　Pinpoint SALISBURY
　　　　T.M.G. *244°*.　G/S *145* k.　W/V *321°/43* k.
　　　　S/c OKEHAMPTON with new W/V.
　　　　Co. *272°* (T)　　*283°* (M)　　*278°* (C)
　　　　G/S *136* k.　Distance *85* n.m.　E.T.A. *0901*

0834　D.R.　Lat. *50° 58'* N.　Long. *2° 22'* W.
　　　　Ordered to S/c 155° LIZARD 20'
　　　　Co. *247°* (T)　　*259°* (M)　　*254°* (C)
　　　　G/S *154* k.　Distance *126* n.m.　E.T.A. *0923*

0904　D.R.　Lat. *50° 11'* N.　Long. *3° 57'* W.
　　　　START bears 062° by Observer's compass
　　　　EDDYSTONE bears 310° by Observer's compass
　　　　Co. of aircraft by Observer's compass 257°

　　　　Dev. Observer's compass *2°* E.
　　　　Bearing START *064°* (M)　　*052°* (T)
　　　　Bearing EDDYSTONE *312°* (M)　　*300°* (T)

Hours
0904 Fix. Lat. _50° 04'_ N. Long. _3° 59'_ W.

S/c SWANSEA assuming W/V 345°/35 k.

Co. _357°_ (T) _009°_ (M) _012°_ (C)

G/S _126_ k. Distance _92_ n.m. E.T.A. _0948._

Description of the Plot: (The answers, which should be checked by the student, are printed above in the spaces in italics.)

0800. We join HESTON to OKEHAMPTON on the chart, so finding Tr. to be made good to be 252° T. With the given T.A.S. and W/V, and using a scale of 1 mm. to 1 k., we draw a triangle of velocities from which we find we must steer a Co. 259° T. to make good the Tr. 252°. Variation from chart and deviation from curve give the equivalent courses as 270° M and 265° C.

The Drift (7° P) is just the difference between Co. and Tr.

From the triangle of velocities we find G/S 146 k., and on the chart we measure the distance HESTON–OKEHAMPTON as 141 n.m. A simple division sum then gives the time to cover 141 n.m. at 146 k.—namely, 58 min. Hence E.T.A. = 0858 hrs.*

0824. Evidently the assumed wind velocity was incorrect, or the wind has changed since the aircraft left HESTON, for at 0824 we are over SALISBURY, which is not on the track we were supposed to be making good.

By joining HESTON to SALISBURY we find the track made good since leaving HESTON to be 244°. Also the distance from HESTON to SALISBURY is 58 n.m. Hence we find by a division sum that the G/S has been 145 k.

With Tr. 244° T, G/S 145 k., Co. 259° T, air-speed 160 k., we now draw a triangle of velocities which gives us a W/V of 321°/43 k.

---

* In practice, problems involving triangles of velocity are usually solved by an instrument which mechanically constructs the triangle. The division sum to find E.T.A. is worked by means of a circular slide-rule on the back of the instrument.

Using this new W/V * we now draw yet another triangle of velocities to find what course to steer to make good the track from SALISBURY to OKEHAMPTON. The new Co. is found to be 272° T. The new G/S is 136 k., while the distance SALISBURY-OKEHAMPTON is found to be 85 n.m. To cover 85 n.m. at 136 k. will take 37 min. Hence new E.T.A. is 0824 + 37 min. = 0901 hrs.

0834. Ten minutes after setting the new course for OKEHAMPTON the aircraft receives orders to S/c for 155° LIZARD 20′. At this time the D.R. position is 10 min. run, at G/S 138 k., on the track-line SALISBURY-OKEHAMPTON. D.R. 50° 58′ N., 2° 22′ W.

We join this D.R. position to 155° LIZARD 20′, and find that we shall have to make good a Tr. 231°. We assume a W/V as found, namely 321°/43 k. Then, with our T.A.S. of 160 k. we draw a triangle of velocities giving Co. to steer 247° T and G/S 154 k.

The distance to be covered is found to be 126 n.m., and the time to cover that distance at the ground-speed 154 k. is 49 min. Hence the new E.T.A. is 0834 + 49 min.=0923.

0904. After ½ hr. the D.R. position is 154/2=77 n.m. along the track-line to 155 LIZARD 20. At this time two simultaneous bearings are taken with the Observer's compass. We can find the true bearings of the points by either of the following methods :

(i) Co. aircraft 257° C by Observer's compass.   .
    Co. aircraft 259° M.
    Hence   2° E. is the deviation of the Observer's compass.
    Application of this deviation and the variation 12° W. to the bearings gives the true bearings : START 052°, EDDYSTONE 300°.

---

* This, of course, is not the only possible procedure. The navigator may have a forecast wind for the latter part of his course which he prefers to use rather than the wind he has just found. Or he may have a weather forecast which indicates that the wind he has just found is unlikely to hold good for the remainder of his journey.

(ii) Co. aircraft by Observer's compass   = 257°.
Bearing of START by Observer's compass = 062°.

Hence Relative Bearing of Start is Green 165°. If this is applied to the True Co. 247°, True bearing of START is found to be 052°. The relative bearing, and thence the true bearing of EDDYSTONE may be found in the same way.

On receiving orders at 0904 to S/c SWANSEA we join the fix we have just obtained to SWANSEA, and so find the track to be made good. This is found to be 000°. With this track, the W/V 345°/35 k., and T.A.S. 160 k. we now draw a triangle of velocities which gives Co. to steer 357° T and G/S 126 k. The distance from the fix to SWANSEA is measured on the chart and found to be 92 n.m. From this and the G/S 126 k. we work out the time of the last leg of the run to be 44 min. and so get an E.T.A. 0948.

EXERCISE VII A

1. At 1400 hrs. you are at CROYDON and are ordered to S/c S. PETER PORT. T.A.S. 170 k. W/V 280°/30 k. Find:

      (a) Compass course to steer.
      (b) G/S.   (c) Distance.   (d) E.T.A.
      (e) D.R. posn. at 1421 hrs.   [A]

2. Find compass course to steer to make good track from RENNES to BRISTOL. T.A.S. 180 m.p.h. W/V 040°/35 m.p.h. Find also G/S, distance, and E.T.A. if you leave RENNES at 0930 hrs.

    What is the D.R. posn. at 1015 hrs.?   [A]

3. 1130 hrs. 245° ST. GOVENS HD. 15 n.m.
S/c SOUTHAMPTON. T.A.S. 165 k. W/V 180°/15 k.
Co._____   (T) _____   (M) _____   (C)
G/S_____   Distance_____   E.T.A. _____
D.R. posn. 1205 hrs._____   [A]

4. At 1015 hrs. you are at LINCOLN and ordered to s/c EXETER. T.A.S. 170 k.   W/V 350°/20 k.   Find (*a*) Compass course to steer (*b*) G/S.   (*c*) Distance   (*d*) E.T.A.   (*e*) D.R. posn. at 1035 hrs.   [*M*]

5. Find Compass course to steer to make good track from OXFORD to ESSEN.   T.A.S. 180 m.p.h.   W/V 005°/30 m.p.h.

Find also G/S, distance, and E.T.A. if you leave OXFORD at 2115 hrs.   What is the D.R. posn. at 2135 hrs. ?   [*M*]

6. 0815 hrs.   120° FLAMBOROUGH 20 n.m.

S/c HESTON.   T.A.S. 170 k.   W/V 285°/35 k.

Co._____   (T) _____   (M) _____   (C)

G/S_____   Distance _____   E.T.A._____

D.R. posn. 0855 hrs._____   [*M*]

EXERCISE VII B

1. 1420 hrs.   WINCHESTER.   Steering Co. 255° by compass. T.A.S. 150 k.

1440 hrs.   Pinpoint DORCHESTER.

T.M.G._____   G/S_____   W/V_____   [*A*]

2. 0600 hrs.   ALDERNEY LT.   Steering Co. 055° C T.A.S. 165 k.

0625 hrs. Pinpoint ST. CATH. PT.

T.M.G._____   G/S_____   W/V_____   [*A*]

3. 1610 hrs.   C. D'ANTIFER.   Co. 307° C   T.A.S. 150 k.

1650 hrs.   Pinpoint PORTLAND LT.

T.M.G._____   G/S_____   W/V_____   [*AM*]

4. 2220 hrs.   UTRECHT.   Co. 275° C   T.A.S. 165 k.

2314 hrs.   Pinpoint SOUTHWOLD LT.

T.M.G._____   G/S_____   W/V_____   [*M*]

5. 1000 hrs.   ST. BRIEUC.   Co. 065° C   T.A.S.   175 k. W/V 275°/20 k.

Tr._____   G/S   DR. 1025 hrs.   [*A*]

6. 1015 hrs. NORWICH.   Co. 125° (C)   T.A.S. 180 k.
W/V 000°/32 k.
Tr. _____   G/S   D.R. 1100 hrs. _____   [*M*]

EXERCISE VII C

1. 2015 hrs.   CAMBRIDGE.   S/c DÜSSELDORF.
T.A.S. 165 k.   W/V 345°/25 k.
Co. _____   (T) _____   (M) _____   (C)
G/S_____   Distance _____   E.T.A. _____
    2040 hrs.   Pinpoint SHIPWASH.
T.M.G. _____   G/S _____   W/V_____
        S/c DÜSSELDORF with new W/V.
Co._____   (T)_____   (M) _____   (C)
G/S_____   Distance_____   E.T.A._____
    2130 hrs.   D.R._____   [*M*]

2. 1230 hrs.   READING.   S/c I. VIERGE.
T.A.S. 150 k.   W/V 350°/15 k.
Co. _____   (T) _____   (M) _____   (C)
G/S _____   Distance _____   E.T.A. _____
    1300 hrs.   Pinpoint ANVIL PT.
T.M.G._____   G/S _____   E.T.A. _____
    1335 hrs.   D.R. _____   [*A*]

3. 1840 hrs.   FLERS.   S/c FALMOUTH.
T.A.S. 180 m.p.h.   W/V 200°/20 m.p.h.
Co. _____   (T) _____   (M) _____   (C)
G/S_____   Distance_____   E.T.A._____
    1910 hrs.   Pinpoint LA CORBIÈRE.
T.M.G._____   G/S_____   W/V_____
        S/c FALMOUTH with new W/V.
Co. _____   (T) _____   (M) _____   (C)
G/S _____   Distance _____   E.T.A. _____
    1930 hrs.   D.R. _____   · [*A*]

4. 1530 hrs.   SHEFFIELD.   S/c LIÉGE.
T.A.S. 200 m.p.h.   W/V 260°/21 m.p.h.
Co._____   (T)_____   (M)_____   (C)
G/S_____   Distance_____   E.T.A._____
    1615 hrs.   Pinpoint SOUTHWOLD.
T.M.G._____   G/S_____   W/V_____
      S/c LIÉGE with new W/V.
Co._____   (T)_____   (M)_____   (C)
G/S_____   Distance_____   E.T.A._____
    1639 hrs.   D.R._____

[*M*]

5. 1625 hrs.   RENNES.   S/c CARDIFF.
T.A.S. 175 k.   W/V 085°/18 k.
Co._____   (T)_____   (M)_____   (C)
G/S_____   Distance_____   E.T.A._____
    1651 hrs.   Pinpoint LA CORBIÈRE.
T.M.G._____   G/S_____   W/V_____
      S/c CARDIFF with new W/V
Co._____   (T)_____   (M)_____   (C)
G/S_____   Distance_____   E.T.A._____
    1730 hrs.   D.R._____

[*AM*]

EXERCISE VII D

1. 1830 hrs.   READING.   S/c MORLAIX.
T.A.S. 165 k.   W/V 270°/20 k.
    1854 hrs.   ANVIL PT. bore 297° (C).   Dev. 4° E.
            NEEDLES bore 042° (C).   Dev. 4° E.
T.M.G._____   G/S_____   W/V_____
      S/c BREST using W/V just found.
Co._____   (T)_____   (M)_____   (C)
G/S_____   Distance_____   E.T.A._____
    1920 hrs.   D.R._____

[*A*]

2. 1030 hrs.   Oxford.   S/c St. Brieuc.
T.A.S. 150 k.   W/V 080°/25 k.

Co. _____   (T)_____   (M) _____   (C)
G/S_____   Distance_____   E.T.A. _____

    1100 hrs.   St. Cath. bore 087° (C).   Dev. 3° W.
               Needles bore 001° (C).   Dev. 3° W.

          Fix :   Lat. _____   Long. _____

T.M.G. _____   G/S _____   W/V _____
     S/c Rennes using new W/V.

Co. _____   (T)_____   (M) _____   (C)
G/S_____   Distance_____   E.T.A. _____

    1135 hrs.   D.R. _____   [M]

3. 1530 hrs.   200° Beachy Hd.   20'.   Co. 276° (C).
T.A.S.   170 k.

    1608 hrs.   Dorchester.
T.M.G._____   G/S _____   W/V_____
     S/c Chepstow.

Co._____   (T)_____   (M) _____   (C)
G/S_____   Distance_____   E.T.A. _____

    1620 hrs.   D.R._____   [A]

4. 1832 hrs.   Caen.   S/c Bristol.
T.A.S.   180 k.   W/V 095°/25 k.

Co._____   (T) _____   (M)_____   (C)
G/S_____   Distance_____   E.T.A. _____

    1857 hrs.   St. Cath. bore 028° (C).   Dev. 3° W.
    1905 hrs.   Anvil Pt. bore 298° (C).   Dev. 3° W.

         Fix :   Lat. _____   Long._____

T.M.G. _____   G/S _____   W/V_____
     S/c Heston using W/V just found.

Co. _____   (T) _____   (M)_____   (C)
G/S _____   Distance_____   E.T.A._____

    1920 hrs.   D.R. _____   [AM]

EXERCISE VII E (Revision)

1. Find the Ch. Lat. and Ch. Long. from F (12° 43' N., 02° 35' E.) to T (25° 25' N., 11° 54' W.).

2. How far is it in nautical miles :

    (a) From 00° 00', 03° 12' W. to 00° 00', 09° 47' E. ?

    (b) From 23° 38' S., 48° 12' E., to 12° 49' S., 48° 12' E. ?

3. Express the distances found in Question 2 (a) and (b) in statute miles.

4. Construct a time-distance scale for a 1/500,000 map for ground speeds ranging from 150 m.p.h. to 250 m.p.h.

5. Write out as many standard abbreviations as you can remember.

6. Copy and complete the following :

Track	Drift	True Co.	Var.	Mag. Co.	Dev.	Comp. Co.
(a) 117° T	18° S		12° W.		3° E.	
(b)	10° P		11° E.		2° W.	297°
(c) 204° T		194°		180°		177°

CHAPTER VIII

* RELATIVE MOTION

THE student will perhaps best understand what is meant by "Relative Velocity" if he looks at the subject from more than one point of view.

(i) *As apparent motion.* If when you are travelling in a train at, say, 20 m.p.h. East, another train travelling at 30 m.p.h. overtakes you, the second train will appear to you to be moving forward past you at 10 m.p.h. The velocity of the second train relative to your train is 10 m.p.h. in an easterly direction.

20 k . B

30 k ↓
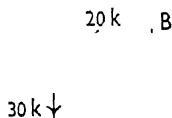
If the second train passed your train travelling in the opposite direction, its velocity relative to your train would be 50 m.p.h. in a westerly direction.

A 20 k

FIG. 45

Now suppose you are travelling East in a boat, A (Fig. 45), at 20 knots, and you observe another boat, B, which is travelling South at 30 knots. Then B will appear to you to be moving towards you in a direction, BD, somewhere between North and East, while she will be seen to be *heading* South. In fact, the boat B will have, to you in A, the same apparent motion as if A were standing still while B was heading South across a current of 20 knots flowing in a westerly direction. The crablike apparent motion of B is very striking and has to be seen to be fully realized.

* See note on page xi.

If B were stationary and you passed her on your easterly course at 20 knots, B would appear to be moving *West* at 20 knots, just as telegraph poles appear to move with the speed of the train in the opposite direction. If B, instead of being stationary, is moving South at 30 knots, we shall have to add this 30 knots South to the 20 knots West to get the velocity of B relative to A, the addition, of course, being vectorial. This addition is performed in Fig. 45 by means of the triangle BCD. In this triangle BD represents the velocity of B relative to A.

(ii) *As rate of change of relative position.* At a given time let the positions of the two boats be A_1, B_1 (Fig. 46). Then an hour later A will have moved to A_2, 20 n.m. East of A_1, while B will have moved to B_2, 30 n.m. South of B_1.
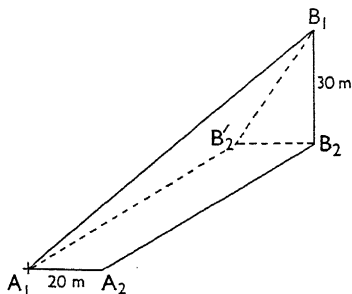
B's position relative to A at the beginning of the hour is given by the bearing and distance of B_1 from A_1. At the end of the hour it is the bearing and distance of B_2 from A_2 that gives the position of B relative to A.

FIG. 46

Through A_1 draw a line parallel to A_2B_2, meeting a line through B_2 parallel to A_2A_1 at B_2'.

Then $A_1B_2'B_2A_2$ is a parallelogram. Therefore, B_2' has the same position relative to A_1 (*i.e.* same bearing and distance) as B_2 has relative to A_2.

The change of relative position of B with regard to A during the hour has therefore been the same as if *A had remained at A_1 and B had moved from B_1 to B_2'.*

The distance B has travelled relative to A during the hour is, therefore, B_1B_2', and the length of B_1B_2' in miles

is the relative speed (of B with regard to A) in m.p.h., while the direction of the relative motion is that of B_1B_2'.

Comparison of Fig. 46 with Fig. 45 will show the student that the triangle $B_1B_2B_2'$ corresponds to the triangle BCD. In each case *we find the velocity of B relative to A by adding (vectorially) to B's velocity the opposite of A's velocity.*

(iii) *As a difference or sum of two vectors*

(a) Given an object A moving with velocity V_A and another object B moving with velocity V_B, we define the velocity of B relative to A as $V_B - V_A$, the subtraction being done vectorially. If the student will consider the case of one train overtaking another, he will see that the above definition is merely a more general statement of how to find relative velocity.
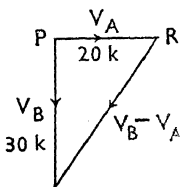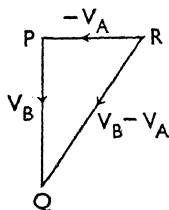

FIG. 47   FIG. 48

Now in Fig. 47

Vector PR $+$ Vector RQ $=$ Vector PQ

Hence

Vector RQ $=$ Vector PQ $-$ Vector PR

$= V_B - V_A$

$=$ Velocity of B relative to A

(b) We can write $V_B - V_A = V_B + (- V_A)$. So, to find the velocity of B relative to A we add (vectorially) to V_B the opposite of V_A. See Fig. 48, compare it with Fig. 47, and compare both figures with Figs. 45 and 46.

The simplest way to find the velocity of one object B relative to another object A is to add to B's actual velocity (*i.e.* B's velocity relative to the Earth) *A's velocity reversed.* Throughout this chapter that is the method we shall adopt.

The student should now draw a diagram to convince himself that :

The Velocity of A relative to B is equal in magnitude and opposite in direction to the Velocity of B relative to A.

Relative Path

Suppose at a given time our two ships A and B are 50 n.m. apart, B being on a bearing 050° from A (Fig. 49).

Using any scale of speeds, we construct the triangle BCD in which BC is A's velocity reversed and CD is B's velocity.

BD represents the velocity of B relative to A, and BX is the *path of* B *relative to* A.

So far as the relative motion of the two ships is concerned, we can think of A as fixed while B moves at velocity BD along the relative path BX.

The ships will not meet one another, the nearest approach being when B is at N (AN perpendicular to BX) on the relative path.

FIG. 49

We could have solved the relative motion problem by drawing the velocity triangle AEF in which AE represents B's velocity reversed, AF represents the velocity of A *relative to* B, and AY the relative path. We can then *think of* B *as fixed while* A *moves at velocity* AF *along* AY.
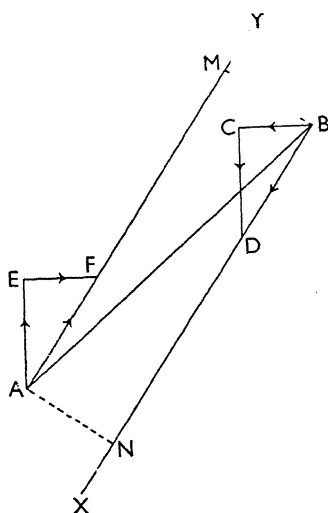
It is easy to prove that the two relative paths, BX and AY, are parallel.

The nearest distance A would get to B would be BM, where BM is perpendicular to AY. Evidently BM = AN, as should be the case.

Line of Constant Bearing

A special and important case is when the relative path BX (see Fig. 49) passes through A. In that case, of course, the relative path AY would pass through B. The bearing of B from A would be angle BDC = 34° approximately.

Consider what this means. B's velocity relative to A is along BA. B is moving (relatively) directly towards A. B will, therefore, continue to bear 034° from A. The bearing of each ship from the other will be constant. In such case we call the relative path (BA or AB) a " Line of Constant Bearing."

The important feature of the constant-bearing case of relative velocity is that if two ships or aircraft are approaching one another on a line of constant bearing they will ultimately meet.

Thus in the case we have been considering both A and B would arrive at I (Fig. 50) at the same time. Indeed, this
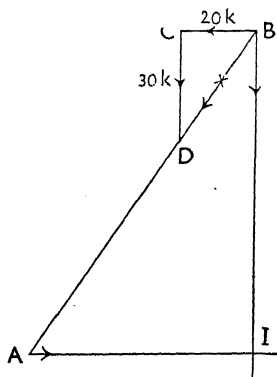

FIG. 50

follows from the fact that triangle BCD is similar to triangle AIB. Hence

$$\frac{BI}{CD} = \frac{AI.}{CB}$$

But $\dfrac{BI}{CD}$ = time taken by B to reach I, and

$\dfrac{AI}{CB}$ = time taken by A to reach I.

Therefore the ships will arrive at I simultaneously. We should say that B had " intercepted " A (or that A had intercepted B), and we call I the Point of Interception. Sometimes I is called the " Geographical Position of Interception " (abbrv. G.P.I.).
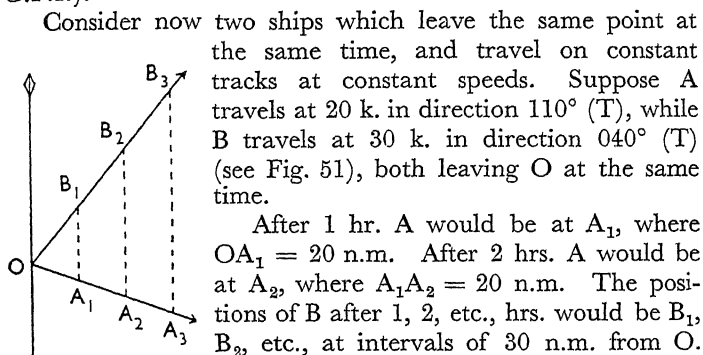
Consider now two ships which leave the same point at the same time, and travel on constant tracks at constant speeds. Suppose A travels at 20 k. in direction 110° (T), while B travels at 30 k. in direction 040° (T) (see Fig. 51), both leaving O at the same time.

FIG. 51

After 1 hr. A would be at A_1, where $OA_1 = 20$ n.m. After 2 hrs. A would be at A_2, where $A_1A_2 = 20$ n.m. The positions of B after 1, 2, etc., hrs. would be B_1, B_2, etc., at intervals of 30 n.m. from O. It is easy to prove that A_1B_1, A_2B_2, A_3B_3, etc., are all parallel to one another, so that each ship is on a constant bearing from the other.

Opening and Closing on a Constant Bearing

Example : An aircraft carrier is steering 075° (T) at 25 k., and there is no tide or current. An aircraft, T.A.S. 120 k., is to leave the aircraft and patrol on a constant bearing 160° (T). What course must the aircraft steer ?

(i) *No Wind.* In Fig. 52, A is the carrier, and AX is the line of constant bearing, 160°, along which the aircraft is to move relative to the carrier. (It is usual to mark a line of constant bearing with a cross—two opposed arrowheads.)

AR represents, on any suitable scale, the velocity of the carrier reversed.

With R as centre, strike an arc, radius 120 k. on the speed scale, cutting AX at S.

Then the direction of RS is the true course the aircraft must steer.

The velocity of the aircraft relative to the carrier will be in direction AX, and the speed at which the aircraft separates from the carrier is represented by AS on the scale of speed.

After a time the aircraft is ordered to rejoin the carrier. To find the course to rejoin, produce XA backwards to Y, and, with compasses opened to the T.A.S. (length RS) and centre R, strike arc cutting AY at T.

FIG. 52

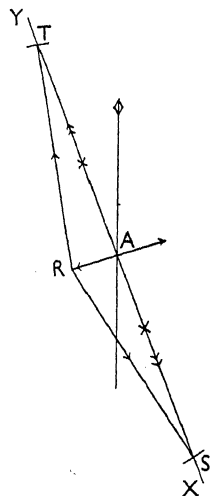The direction of RT gives the course to rejoin while AT gives the speed of rejoining.

(ii) *With Wind.* Suppose now there is a wind of 25 k. blowing from 020°. The construction to find the course to steer on the outward patrol is shown in Fig. 53, where AR represents carrier's velocity reversed, RW represents the Wind Velocity, and WS represents the T.A.S.

The course to steer is given by the direction of WS.

For, if the aircraft steers course WS at 120 k., its actual velocity over the Earth's surface, when we allow for the wind, is represented by RS. RS added vectorially to AR, the carrier's velocity reversed, gives, as the velocity of the

aircraft relative to the carrier, AS, which is along the line
of constant bearing.

Fig. 53

Fig. 54

The whole problem of opening and closing on a constant
bearing is solved in Fig. 54. The data assumed are those
used in the examples just given.

The actual path followed by the aircraft is the line AP
which is parallel to the line marked " track out." At some
point, P, the aircraft turns to rejoin the carrier, and then
flies along the return path PA', which is parallel to the line
marked " track in." While the aircraft flies along AP and
PA', the carrier travels from A to A' arriving at A' at the
same time as the aircraft arrives there.

Interception

(i) Interception of a ship by an aircraft.

In order to set course to intercept a ship we must know
the ship's track and speed and the position of the ship

relative to the point from which the aircraft is to leave on the intercepting run. With that information, and knowing the W/V and the T.A.S. of the aircraft, we find the course to intercept by the constant bearing diagram discussed above.

As the speed of an aircraft is always much greater than the maximum speed of a ship, it is theoretically always possible for an aircraft to intercept a ship.

(ii) Interception of aircraft by aircraft.

Example : At 0800 hrs. aircraft A is flying on a course 090° (T) at T.A.S. 150 k. At the same time aircraft B is 50 n.m. on bearing 140° (T) from A. We will consider the interception of aircraft A by aircraft B.

Note first that the relative motion of the two aircraft will not be affected by the wind provided both aircraft are influenced by the same wind. In solving the relative motion problem, therefore, we need not take any account of the wind.

On any suitable scale of distance plot the positions, A and B, of the aircraft at 0800 hrs. (Fig. 55.) From B set off, on a suitable scale of speeds,

Fig. 55

A's velocity (150 k. in direction 090°) reversed (BC).

To find the course to intercept A we have to strike an arc on the line of constant bearing AB, with centre C and radius T.A.S. of B. Several possibilities arise according to the T.A.S. at B's disposal.

(*a*) B's T.A.S. greater than A's. *E.g.* B's T.A.S. 170 k. The arc can be struck at D_1 or D'_1. The course CD_1 will
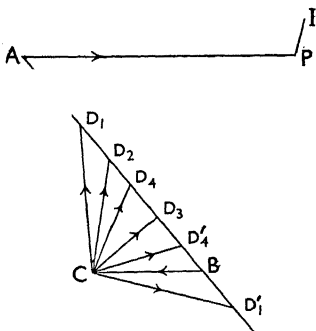
enable B to intercept A, the speed of approach being BD_1. But Course CD'_1 produces a relative velocity BD'_1 which will lead B *away* from A. Thus in this case there is one, and only one, course for B to intercept A.

(*b*) B's T.A.S. equal to that of A. Here the arc, centre C, will cut the line of constant bearing at B or D_2. Obviously if B follows the course CB it is simply moving parallel to A and therefore cannot intercept A. But the course CD_2 will enable B to intercept A. Here, then, there is just one course enabling B to intercept the other aircraft.

(*c*) B's T.A.S. less than that of A's. Suppose, for example, that B moves at a T.A.S. 140 k. In this case the arc can be struck at either D_4 or D'_4. Either of the courses CD_4 or CD'_4 will lead to interception. Clearly the course that would usually be followed would be CD_4, since this gives a much greater rate of approach (viz. BD_4) than the other course (rate of approach BD'_4) gives.

(*d*) If we suppose B to have air-speeds less than A's 150 k. we shall get two solutions of the problem, as for 140 k., until the T.A.S. gets down to 115 k. For that T.A.S. it will be found that B's course (CD_3) is perpendicular to the line of constant bearing, and there is accordingly only *one* course for B to follow to intercept A. If B has a T.A.S. less than 115 k. no arc can be struck on AB with centre C and radius B's T.A.S., and it is therefore, for such air-speeds, not possible for B to intercept A.

In the above we have assumed that A keeps on a constant course at a constant speed. If A wishes to avoid interception by B it can do so, *provided A's T.A.S. is not less than B's*, by altering course. But if B has a greater T.A.S. than A it can intercept A in whatever direction A may decide to fly.

To find the actual position where interception will take place, we must make allowance for the effect of the wind.

Suppose the W/V is 200°/30 k., and that B's T.A.S. is 170 k. From our velocity triangle (Fig. 55) we find

$$\text{Speed of closing} = BD_1 = 223 \text{ k.}$$
$$\text{Distance to close} = 50 \text{ n.m.}$$
$$\text{Time to close} = 13\tfrac{1}{2} \text{ min.}$$

Then at the time of interception the air position of A will be P where AP = run for $13\tfrac{1}{2}$ min. at 150 k. = 34 n.m. nearly.

The actual point of interception will be I where PI is in the direction towards which the wind is blowing, and PI = wind movement for $13\tfrac{1}{2}$ min. at 30 k. = 7 n.m. nearly.

An alternative procedure for finding the point of interception would be to plot the actual paths of A and B, by allowing for the effect of the wind upon each aircraft. Then the point of interception would be where these paths intersect.

Radius of Action

The " Radius of Action " is the maximum distance an aircraft can travel away from its base before it must begin its return journey, given that the total duration of the patrol must not exceed a certain time.

The radius of action will, of course, depend partly upon the T.A.S. of the aircraft. It will also depend upon the wind speed and the angle between the wind direction and the direction in which it is desired that the patrol should be made. Finally it will depend upon the length of time the aircraft can be away from its base.

We shall consider the two cases (i) where the base is fixed, (ii) where the base is moving (*e.g.* when the patrolling aircraft is based upon an aircraft carrier which is moving during the patrol).

(i) *Fixed base*

Example : Find the Radius of Action for a 5-hr. patrol

by an aircraft of T.A.S. 120 k., on a bearing 100° (T), the W/V being 020°/20 k.
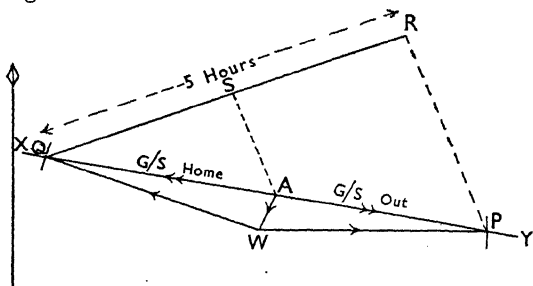
See Fig. 56.

<div align="center">FIG. 56</div>

Through A, the base, draw XY, the line of bearing 100°.

Draw the wind vector, AW, and with centre W, radius T.A.S., strike arcs at P and Q.

The ground-speed on the outward journey is given by AP, that on the homeward journey by AQ.

If R is the Radius of Action, O the G/S on outward journey, and H the G/S on homeward journey,

$$\text{Time out} \times O = R = \text{Time home} \times H$$

Hence $\dfrac{\text{Time out}}{\text{Time home}} : \dfrac{H}{O}$. (1)

Using this relation we can find, by a simple geometrical construction, how long the aircraft can fly on the outward journey before it is necessary to turn back.

On any scale of time (*e.g.* 1 in. to 1 hr.) draw QR to represent 5 hours, at any angle with QP. Join PR and through A draw AS parallel to PR, meeting QR at S.

Then, on the scale of time, QS is the time on the outward journey.

In this method there is no need to measure AP and AQ.

If, however, we measure those and find the Out and Home speeds, O and H, we can find the Radius of Action by a simple formula, as follows :

Let P be the total time of the patrol (5 hrs. in the foregoing example).

Let t be the time in the outward journey.

Then time on home journey $= P - t$.

Equation (1) above now gives us

$$\frac{t}{P - t} = \frac{H}{O}$$

$$\therefore \quad \frac{t}{P} = \frac{H}{O + H}$$

$$\therefore \quad t = \frac{PH}{O + H}$$

Now the Radius of Action, R,

$$= Ot$$

$$= \frac{OPH}{O + H}$$

$$\text{or} \quad R = P\frac{OH}{O + H} \quad . \qquad . \quad (2)$$
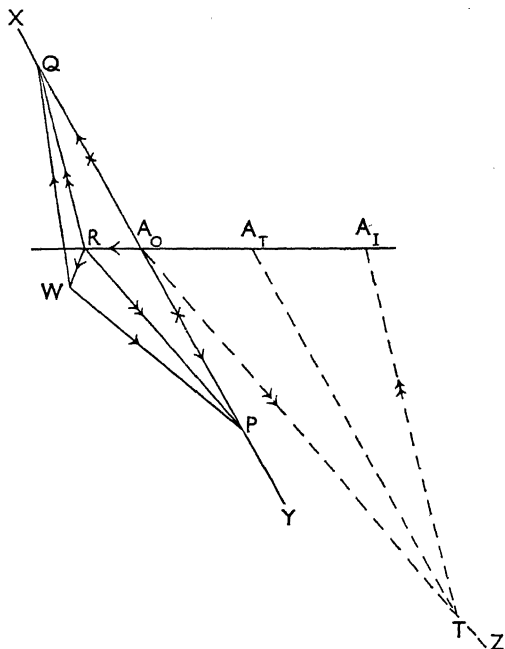
Fig. 57

Draw $A_0R = 30$ k., on any scale of speed, being carrier's velocity reversed.

RW is the wind vector. XY is the line of constant bearing running in direction 150°.

WP and WQ are the T.A.S. vectors for outward and homeward journeys respectively.

The track out is given by the direction of RP. Hence if we draw A_0Z parallel to RP, A_0Z will be the actual outward path of the aircraft.

The return track is the direction of RQ. We therefore draw, through A_1, A_1T parallel to QR and cutting A_0Z at T.

T is the point at which the aircraft turns back. The time to turn (abbrv. T.T.T.) may be found by calculating the time to travel distance A_0T at speed RP.

The position of the carrier at T.T.T. is A_T, where A_TT is parallel to XY.

Effect of Wind upon Radius of Action

We will consider only the case of a fixed base. In Fig. 58, A is the base, QAP the direction of the patrol, and AR the
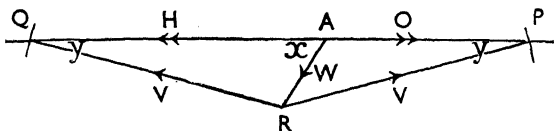

Fig. 58

wind vector. With R as centre we strike arcs, radius T.A.S. (V), at P and Q. Let W be the Wind Speed. Let the angle between the Wind Direction and the track (angle QAR) be x, and angle APR be y.

Since RQ = RP, angle AQR = y

Speed on outward journey = AP = O

Speed on homeward journey = AQ = H

Then $O = V \cos y - W \cos x$

$H = V \cos y + W \cos x$

Now the radius of action is $R = P \dfrac{OH}{O + H}$, where P is the total time of patrol.

$$\therefore \ R = P \frac{(V \cos y - W \cos x)\,(V \cos y + W \cos x)}{V \cos y - W \cos x + V \cos y + W \cos x}$$

$$= P \frac{V^2 \cos^2 y - W^2 \cos^2 x}{2\,V \cos y}$$

Now $\sin y = \dfrac{W \sin x}{V}$, so that $\cos y = \dfrac{\sqrt{V^2 - W^2 \sin^2 x}}{V}$

Substituting in the equation for R we now get

$$R = \frac{P(V^2 - W^2)}{2\sqrt{V^2 - W^2 \sin^2 x}}$$

From this formula we can see that, for a given wind speed, the radius of action will be greatest when the denominator is least ; that is, when sin x, and therefore x, is greatest. That is to say, the radius of action is greatest when the wind is at right angles to the track. The radius is least when the wind is along the track ($x = 0°$ or $180°$). The greatest and least values of the radius of action are, respectively :

$$\frac{P(V^2 - W^2)}{2\sqrt{V^2 - W^2}}, \; i.e. \; \tfrac{1}{2}P\sqrt{V^2 - W^2}$$

and

$$\frac{P(V^2 - W^2)}{2\sqrt{V^2}}, \; i.e. \; \tfrac{1}{2}P\frac{V^2 - W^2}{V}$$

Critical Point

An aircraft is flying from one base, A, to a second base, B. On the way there may be a mishap, such as the disabling of one of the engines resulting in a lowering of the air-speed. It is then important for the aircraft to reach a base as quickly as possible, and the question may arise as to whether the aircraft should return to the base A or continue on its journey to B.

The point C between A and B from which it would take the aircraft the same time to return to A as to continue to B is called the " Critical Point."

To determine the position of the Critical Point we first find, from wind velocity and T.A.S., the outward G/S, O, and the return G/S, H, represented respectively by AP and AQ in Fig. 59.
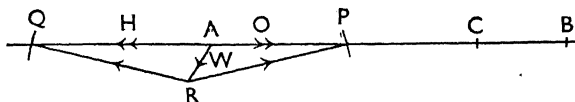

Fig. 59.

Let the distance between the bases be d, and let the critical point be a distance x from A.

Then, time to continue to B from C $= \dfrac{d - x}{O}$

Time to return to A from C $= \dfrac{x}{H}$

These times are equal, so $\dfrac{d - x}{O} = \dfrac{x}{H}$

$$\therefore \; x = d \, \dfrac{H}{O + H}$$

Having found, by the construction in Fig. 59, the values of O and H, we substitute them in this equation, and so find the distance of the Critical Point from A. •

EXERCISE VIII

1. An aircraft carrier is steaming at 28 k. on course 245° (T). At 1100 hrs. an aircraft is 65 n.m. on bearing 175° from the carrier. Assuming T.A.S. 150 k. and W/V 095°/15 k. find the true course the aircraft must steer to join the carrier. Find also the time at which the aircraft reaches the carrier.

2. A carrier is steaming 075° (T) at 30 k. An aircraft is to leave the carrier to patrol on bearing Green 45°. T.A.S. of aircraft 140 k. W/V 180°/18 k.

    1400 hrs. Aircraft leaves carrier. Find true course of aircraft.

    1445 hrs. Aircraft ordered to return. Find how far the aircraft is then from the carrier. Find also the true course the aircraft must steer to return and the time at which it will rejoin the carrier.

3. 0800 hrs. Aircraft carrier in posn. 48° 32′ N., 5° 47′ W., steaming 065° (T) at 28 k.

    0900 hrs. Carrier a/c 347° (T).

    0915 hrs. Aircraft in posn. MWRE 2545 ordered to join carrier. T.A.S. 120 k. W/V 100°/15 k.

Find true course to be steered by aircraft to join carrier. Find also E.T.I. and G.P.I.   [A]

4. 1015 hrs.   Carrier in posn. 195° NEEDLES 20′.   Course 260° (T).   Speed 30 k.

 1115 hrs.   START PT. bore 309° (C).   Dev. 3° E.

 1225 hrs.   EDDYSTONE bore 019° (C).   Dev. 3° E.

  Fix : Lat._____   Long._____

   a/c 240° (T).

 1240 hrs.   Aircraft leaves carrier for I. DE BAS.   T.A.S. 165 k.   W/V 125°/35 k.

 True course of aircraft_____

 1300 hrs.   D.R. posn. carrier : Lat._____   Long._____

   D.R. posn. aircraft : Lat._____   Long._____

Aircraft ordered to rejoin carrier.   Find true course to be steered by aircraft, E.T.I. and G.P.I.   [A]

5. 0930 hrs.   Carrier in posn. 49° 55′ N., 0° 10′ E.

   S/c TORQUAY.   Speed 30 k.   No current.

True course carrier_____

 1200 hrs.   Aircraft leaves to patrol on Red 60°.

T.A.S. 132 k.   W/V 340°/28 k.

True course aircraft_____

 1225 hrs.   Carrier s/c for 180° LIZARD 15′.

True course carrier_____

 1235 hrs.   Lat. carrier_____   Long. carrier_____

 D.R. Lat. aircraft_____   D.R. Long. aircraft_____

  Aircraft ordered to rejoin carrier.

True course to rejoin_____   E.T.I._____   G.P.I._____

                [A]

6. 0615 hrs.   Aircraft carrier in posn. 54° 20′ N., 1° 15′ E. Course of carrier 162° (T).   Speed 30 k.

 0735 hrs.   Aircraft leaves carrier to patrol on Red 90°.

T.A.S. 120 k.   W/V 135°/20 k.

True course aircraft

0835 hrs.   D.R. aircraft : Lat._____   Long._____
                 Aircraft ordered to s/c 214° (T).
                 Track_____   (T).

1040 hrs.   D.R. carrier : Lat._____   Long._____
                 Carrier a/c 204° (T).

1050 hrs.   D.R. carrier : Lat._____   Long._____
                 D.R. aircraft : Lat._____   Long._____
                 Aircraft ordered to rejoin carrier.

True course aircraft_____   E.T.I._____   G.P.I._____ [*M*]

7. At 1400 hrs. aircraft B is 130 n.m. on bearing 180° (T) from aircraft A.
A is steering Co. 120° (T), B is steering Co. 075° (T).
Both aircraft have T.A.S. 120 k. and are influenced by a W/V 270°/30 k.
Find (i) Tr. and G/S of A ; (ii) Tr. and G/S of B ; (iii) Velocity and path of B relative to A ; (iv) distance between aircraft when they are nearest one another ; (v) time at which the nearest approach is made ; (vi) the true course B must set at 1400 hrs. in order to intercept A, if A continues on Co. 120° (T), and the time of interception ; (vii) the true course A must set at 1400 hrs. in order to intercept B, if B continues on Co. 075° (T), and the time of interception.

8. Aircraft A is travelling on Tr. 085° (T) at G/S 140 m.p.h. At 1600 hrs. aircraft B is 40 m. on bearing 140° (T) from A. Find (i) the two courses B may set to intercept A if B's T.A.S. is 125 m.p.h., assuming no wind ; (ii) the least T.A.S. which will enable B to intercept A.

9. An aircraft based at A is ordered to patrol on bearing 235° (T). T.A.S. 180 m.p.h. W/V 339°/32 m.p.h. The aircraft is to keep on constant bearing 235° from A and is to return to A in 4 hrs. Find (i) True course out ; (ii) T.T.T. ; (iii) True course home.

10. What is the radius of action for a 5-hr. patrol on bearing 025° with T.A.S. 200 m.p.h. and W/V 090°/35 m.p.h. ?

11. An aircraft carrier is steaming at 28 k. on Co. 165° (T). An aircraft is ordered to patrol on bearing Green 45°, returning to the carrier in 3 hrs. If the T.A.S. is 150 k. and W/V is 215°/25 k., find (i) aircraft's true course out ; (ii) how long may be spent on the outward journey ; (iii) aircraft's true course home.

12. 1215 hrs.   Carrier in posn. 54° 15′ N., 2° 25′ E.
Co. of carrier 180° (T).   Speed 32 k.
   1250 hrs.   Aircraft leaves carrier to patrol on bearing Red 90°. T.A.S. 165 k. W/V 170° 27 k.   The aircraft is to patrol on a constant bearing as far as possible and rejoin the carrier at 1530 hrs.   Find (i) True course aircraft out ; (ii) T.T.T. and Lat. and Long. aircraft at T.T.T. ; (iii) True course aircraft home ; (iv) Lat. and Long. of carrier when aircraft rejoins.

   Note : The carrier keeps on a constant course at constant speed during the absence of the aircraft.   [M]

13. An aircraft is to fly from Base A to Base B which is 155 m. on bearing 286° from A.   The T.A.S. is 175 m.p.h.   W/V is 180°/29 m.p.h.   Find the distance of the critical point from A.   What would be the distance of the critical point from A if the T.A.S. were 130 m.p.h. ?

14. Prove the following construction to find the radius of action for a 1-hr. patrol from a fixed base :
   Draw a line XY to represent the direction of patrol. From any point A on XY draw AW, the wind vector, and with centre W, radius true air-speed, strike arcs at P and Q on XY.   Draw AR parallel to QW and RS parallel to WA. Then AS is the radius of action required.   (The units of distance and of speed are assumed equal in this construction.)

CHAPTER IX

INSTRUMENTS

No attempt will be made to give a detailed account of the construction of navigational instruments, for that is outside the scope of air navigation. The air navigator does not have to make, or even repair, his instruments. He has to read them, and apply corrections to his readings, and he need know only enough about the principles on which they work to enable him to interpret and correct their readings.

Excluding drawing instruments and instruments for the mechanical solution of problems depending upon triangles of velocities there are three types of instrument upon which the air navigator is particularly dependent, namely, Magnetic Compasses, Altimeters, and Air-speed Indicators.

MAGNETIC COMPASS

Lines of Force

Iron filings scattered near a bar magnet will set themselves along curves as shown by the dotted lines in Fig. 60. These curves run from one pole of the magnet to the other, from the "Red" pole to the "Blue" pole. Near the poles the curves are close together, and there is a concentration of iron filings.

FIG. 60

The curves indicate the direction, at various points around the magnet, in which the magnetic force acts, and it is therefore proper to call the curves "Lines of Force." Through any point near the magnet
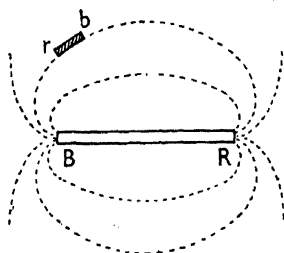
there runs a perfectly definite line of force giving the direction of the magnetic force at that point. Thus suppose we place a little magnet, *rb*, near the big magnet (see Fig. 60). The little magnet will set its axis along the line of force, having its red pole, *r*, towards the blue pole of the big magnet.

We can, then, think of the region around a magnet as full of lines of force. We call such region a " Magnetic Field."

The Earth is an irregular magnet. It behaves magnetically rather as though there were, somewhere inside it, a huge bar magnet, shorter than the Earth's axis in length, and not lying along the Earth's axis, but having its blue pole beneath the ground somewhere in Northern Canada. But this is a very rough, if not somewhat fanciful, way of describing the Earth's magnetism. What the student must grasp (and all he needs to grasp) is that the neighbourhood of the Earth's surface is a magnetic field, the blue part of which is in the Northern, and the red part in the Southern, hemisphere.
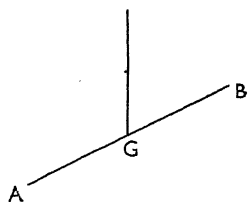
FIG. 61

Suppose a uniform needle were suspended at its centre of gravity, G (Fig. 61). Then the needle could (apart from the effects of twisting in the suspending fibres) be made to rest in any direction pointing N., E., S., or W. ; and it could be level or have either end pointing up or down.

If now we suppose the needle to be magnetized, it would at once set itself along the Earth's line of force. If the experiment were carried out in London in 1942, the needle would set itself in a vertical plane (the " Magnetic Meridian " at London), some 9° W. of True North, while the red pole would dip down, so that the axis of the needle was inclined to the horizontal at an angle of about 70°. This angle is known as " Dip."

Dip : How Counterbalanced

To serve its practical purpose, a compass needle must be horizontal or nearly horizontal. This is achieved by suspending the needle at a point above its centre of gravity.

Thus suppose we suspend the needle at the point P (Fig. 62 (i)), above the centre of gravity, G, of the needle. We may suppose P joined to the needle by short wires PA, PB.

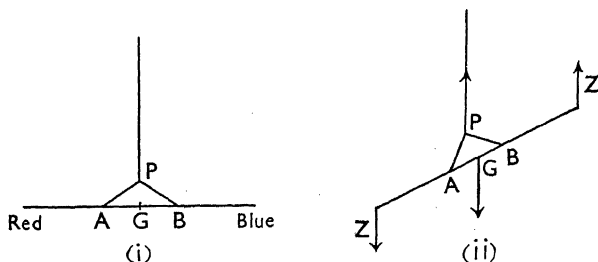Suppose, in both Fig. 62 (i) and Fig. 62 (ii) that the plane of the paper is the plane of the magnetic meridian.

FIG. 62

Under the influence of the Earth's vertical magnetic force (Z) the needle will dip towards the North as in Fig. 62 (ii). The force Z will act downwards on the Red end and upwards on the Blue end of the needle (in the Northern hemisphere). The result is a " couple " tending to turn the needle away from the horizontal position.

But the weight of the needle, acting at G, and the force in the suspending fibre, equal to the weight of the needle and acting at P, produce another couple tending to restore the needle to the horizontal position. The needle will set itself at such an angle that these two couples are equal. In aircraft compasses that angle is commonly 2° or 3°.

It is seen, then, that we can to a large extent overcome the effect of dip by suspending the compass needle *at a point above the centre of gravity* of the needle. The mode of sus-

pension of compass needles is not as described above, but has the same essential quality :

<div align="center">

THE POINT OF SUSPENSION (PIVOT) IS ABOVE THE CENTRE OF
GRAVITY OF THE MAGNET SYSTEM

</div>

Pilot's Compass

In the pilot's type of compass the magnets are suspended from a very light " spider " consisting of a dome with spokes radiating from it (Fig. 63). The figure shows how the spider is pivoted inside the dome. One magnet, PQ, is shown in the figure, though there are usually two or four magnets. The spider is in a bowl which is filled with liquid. The resistance of this liquid to the motion of the spokes of
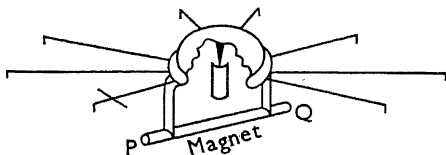
FIG. 63

the spider has a steadying effect on the magnet system. The North end of the spoke which is parallel to the magnet is marked by a cross-line.

Courses are set or read by means of a " Verge Ring." A few moments' study of an actual pilot's compass will suffice to show the student how the verge ring is used. He is advised to practise setting courses on a pilot's compass, which is, for that purpose, most convenient when mounted on a turntable, shaped like an aircraft, and known as a " deviascope."

Observer's Compass

The essential difference between an Observer's Compass and a Pilot's Compass is that the former has no verge ring, and, in place of a " spider," a fully graduated compass card to

which the magnetic needles are attached. The needles are underneath the compass card. Moving on a ring (called an " Azimuth Ring ") round the compass bowl is a sighting device by means of which bearings may be taken, and a prism which brings the part of the compass card just below the " sights " into view, so that the bearing may be read. A quarter of an hour's practice in taking bearings with such a compass is worth any amount of reading about the process, so a fuller description will not be given here.

Northerly Turning Error

Owing to their mode of construction, aircraft compasses are subject to certain errors due to the motion of the aircraft.

For simplicity, suppose the magnet system to consist of one needle, and suppose we are in Northern latitudes where dip is to the North (Fig. 64 (i)). Owing to the tilt *the centre of gravity will be South of the pivot.*

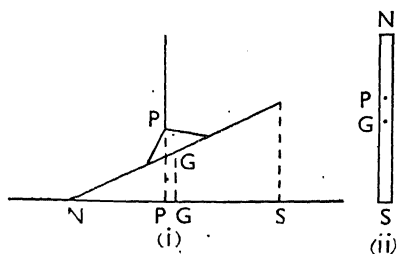Viewed in plan, the system will appear as in Fig. 64 (ii).
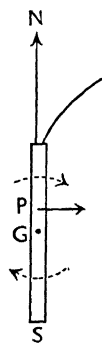

Fig. 64

Fig. 65

Suppose an aircraft steering 000° (Magnetic) turns Eastwards. Then the magnet system is dragged to the East, the drag being applied at the pivot, resulting in rotation of the magnet system clockwise, as shown in Fig. 65, so producing Easterly Deviation.

The swing of G towards the West tilts the plane of the magnet system towards the East. When that occurs, since the plane of the magnet system is no longer perpendicular (or so nearly perpendicular as it was) to the Earth's vertical magnetic force Z, that force has a component in the plane of the magnet system as shown in Fig. 66. This produces further Easterly deviation.
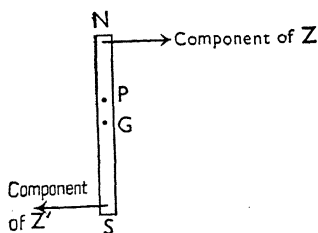

FIG. 66

Thus a turn from Magnetic North to the East produces Easterly deviation. In the same way we can show that a turn from North to West produces Westerly deviation. These deviations are referred to as " Northerly turning error."

If the rate of Easterly turn of the magnet system is less than that of the *aircraft*, the aircraft will appear, according to the compass, to have made an Easterly turn, but less in amount than the turn actually made.

If aircraft and magnet system turn Eastwards at the same rate the compass will indicate no turn.

If the magnet system turns Eastwards more quickly than the aircraft turns, the aircraft will appear, according to the compass, to have turned Westwards.

The student can work out for himself the effect upon the compass of a turn to East or West from a Southerly course. He should also consider what turning errors will be found in Southern (magnetic) latitudes—that is, in parts of the world where the needle dips to the *South*.

FIG. 67

Now consider an aircraft steering course East (Magnetic) which turns to the North (Fig. 67). In this case the mechanical force applied to the magnet system is applied at P *along* GP, and

so has no turning effect upon the system, and there is no deviation. The same would be true of a turn South from East, or North or South from West.

Turning errors of appreciable magnitude are produced only when the aircraft's course is between N.W. and N.E., or S.W. and S.E.

Acceleration and Deceleration Errors

An aircraft is steering East (Magnetic) as shown by the arrow in Fig. 68. The pilot *accelerates* the aircraft. This results in a forward pull on the magnet system at P, while G will lag behind. Result : Easterly deviation. This may be as much as 20° or 30° It can be allowed for only by practice. After the acceleration ceases, the compass needle will settle to its correct position within 1 to 1½ minutes.
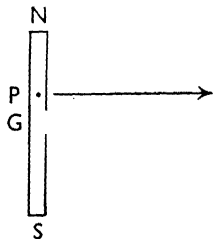
FIG. 68

For *deceleration* on an Easterly course the deviation would be Westerly.

On a Westerly course acceleration will produce Westerly, deceleration Easterly, deviation.

Acceleration or deceleration will have no effect upon the compass when the aircraft is steering a course North (Magnetic) or South (Magnetic). For the force applied at the pivot is then in the line joining the pivot to the centre of gravity, and so has no turning effect.

There will be no appreciable acceleration or deceleration error except when the aircraft is steering courses between N.E. and S.E., or N.W. and S.W.

The student can work out for himself the deviations that will be produced by acceleration or deceleration in Southern Magnetic latitudes, remembering that in that part of the world the centre of gravity of the magnet system will be situated *North* of the pivot.

Liquid Swirl

When a long-sustained turn is made by an aircraft the liquid in the compass bowl may begin to swirl, and this effect may be added, so far as the swirl affects the spider, to the turning error of the compass. Liquid swirl increases the effect in turns from North and decreases effect in turns from South. In short turns, swirl does not arise.

EXERCISE IX A

1. Define :   Magnetic Dip ;   Magnetic Equator ;   North (South) Magnetic latitudes.

2. At what part of the Earth is a magnetic compass subject to no turning or acceleration error ?

3. An aircraft in Northern Magnetic latitude is on Co. 020° M and alters Co. to 335° M. What effect will the turn have upon the magnet system ?

4. Copy and complete the following (working out the answers by rough sketches of the compass needle with positions of pivot and centre of gravity marked).

Aircraft turns . . .	N. to E.	N. to W.	S. to E.	S. to W.
Magnet system turns in North Mag. Lat. .				
Magnet system turns in South Mag. Lat. .				

5. Tabulate the effects of acceleration and deceleration of an aircraft upon the compass for the following cases :

Northern Mag. Lats. $\begin{cases} \text{Accel. E.} & \text{Accel. W.} \\ \text{Decel. E.} & \text{Decel. W.} \end{cases}$

Southern Mag. Lats. $\begin{cases} \text{Accel. E.} & \text{Accel. W.} \\ \text{Decel. E.} & \text{Decel. W.} \end{cases}$

ALTIMETER

Atmospheric Pressure

At any point under the sea there is pressure which, being due to the weight of the water above, increases with depth. On the Earth's surface we live at the bottom of the ocean of air called the Atmosphere. The atmosphere exerts a pressure, at the Earth's surface, of about 15 lb. weight per square inch.

As you ascend from the Earth's surface you have a less and less weight of air above you and therefore the pressure becomes less. If we know the rate at which the pressure falls with increase in height we can determine our height by measuring the pressure. That is the principle of the ALTI-METER.

Units of Pressure

It was formerly the practice to measure atmospheric pressure by the length of a column of mercury which would balance the pressure. If the column were, say, 755 mm. long, the atmospheric pressure was said to be 755 mm. The average pressure at Mean Sea Level is 760 mm.

We now use as the unit of atmospheric pressure the *millibar* defined thus :

1,000 millibars is the pressure corresponding to a column of mercury 750·1 mm. high at 0° C. in latitude 45°.*

This will appear to the student a complicated and arbitrary definition. He will appreciate, however, that there must be some mention of temperature in the definition, since the density of mercury (and therefore the weight of a column of mercury of a given length) varies as temperature varies.

* An alternative definition of a millibar, in which there is no need to refer to temperature or latitude, is : A millibar is a pressure of 1000 dynes per square cm., a dyne being the force required to produce an acceleration of 1 cm. per second per second in a mass of 1 gramme.

Moreover, the force of gravity varies slightly with latitude, being somewhat greater at the poles than at the Equator, and therefore our definition has to state a standard latitude.

The average pressure at Mean Sea Level is 760 mm.

$$\text{In millibars this average pressure} = \frac{760}{750 \cdot 1} \times 1000$$
$$= 1013 \cdot 2 \text{ mb.}$$

The Altimeter

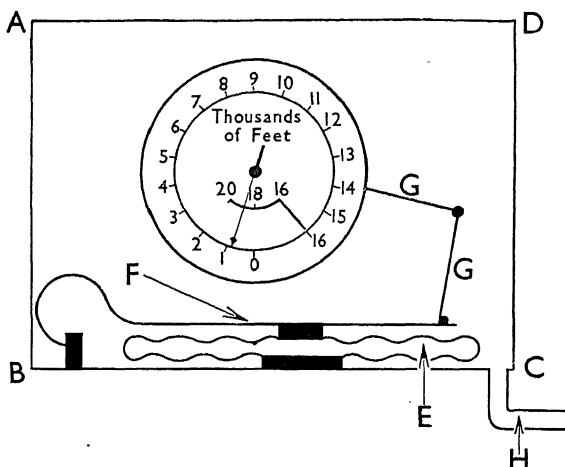The construction of an altimeter is shown diagrammatically in Fig. 69.

Fig. 69

The whole instrument is enclosed in an airtight box ABCD, from which a tube, H, goes to what is called the Static Head (see below).

E is a flat metallic box or capsule, fixed to the container ABCD on one side, and fixed on the other side to a spring F. The capsule E is exhausted of air and would therefore collapse

under the pressure of the air outside it but for the spring F which keeps the walls of the capsule apart.

As the pressure varies (*e.g.* when the aircraft ascends) the wall of the capsule which is attached to F will move. This movement is magnified and communicated by a series of levers (shown diagrammatically by the rods G in the figure) to the pointer on the dial. (In the actual instrument the capsule is placed behind the dial so that the arrangement is much more compact than in the diagram in Fig. 69.)

The Static Head to which reference has been made above is a tube placed on or near a wing, away from the
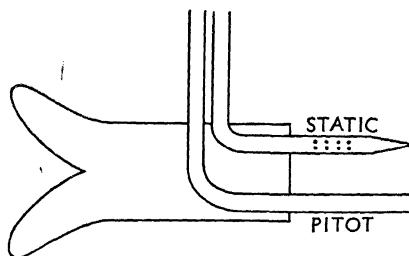
FIG. 70

slipstream. The tube (Fig. 70) is placed parallel to the axis of the aircraft ; the forward end of the tube is closed, but there are several holes, indicated by dots in Fig. 70, in the side of the tube. Side by side with the Static Head is another tube, called a Pitot tube, the two tubes being mounted together as a unit, though the Pitot tube plays no part in the working of the altimeter.

If the capsule of the altimeter were exposed to the air in the cockpit it would be subject to pressure variations due to eddies of air. We want the capsule to be free from any variations of pressure arising out of the motion of the aircraft. It may be assumed that the pressure of the air inside the Static Head is not affected by the motion of the tube through

the air : it is the pressure at that point of the atmosphere at which the aircraft is situated, all effects of motion eliminated, and that is the pressure we want to affect the capsule.

The position of the pointer on the altimeter's dial depends solely upon the atmospheric pressure at the height of the aircraft. But the scale on the dial is not graduated in units of pressure. It is graduated to show height in feet. We have now to consider on what principle the instrument's dial is graduated.

Calibration of Altimeter and Correction of Readings

In order to graduate the dial of an altimeter we must make some assumption as to the rate of decrease of pressure with height. The actual law of decrease of pressure is complicated, and indeed is not constant, for there are continually taking place variations in temperature at various levels of the atmosphere which affect the rate of decrease of pressure with ascent. One or other of two assumptions about the atmosphere is made for purposes of air navigation. They are :

    (i) The Isothermal convention : pressure is assumed to be 1013·2 mb. at mean sea level and temperature is assumed to be 10° C. (50° F.) at all heights.

   (ii) The I.C.A.N. (International Commission for Air Navigation) convention. This assumes mean sea-level pressure 1013·2 mb. and sea-level temperature 15° C. (59° F.). The temperature is assumed to decrease uniformly at 1·98° C. per 1,000 feet up to 36,000 feet, above which it is assumed to remain constant.

Of the two conventions the I.C.A.N. corresponds the more closely to the conditions actually prevailing in the atmosphere.

The theoretical values of the pressure at various heights on the Isothermal and I.C.A.N. assumptions are given in the following table :

Height above sea level (feet)	Pressure in millibars	
	Isothermal	I.C.A.N.
0	1013·2	1013·2
1,000	976·6	977·3
2,000	941·4	942·1
3,000	907·2	908·2
4,000	874·7	875·0
5,000	842·9	843·2
10,000	701·3	696·9
20,000	485·6	465·6
30,000	335·9	301·0

From the table it will be seen that the fall in pressure is not uniform, being (under the Isothermal law) 36·6 mb. for the first 1,000 ft., and 31·8 mb. for the fifth 1,000 ft. Under the I.C.A.N. law the corresponding figures are 35·9 mb. and 31·8 mb. These figures are in fair accord with the following approximate rule :

Pressure falls by 1 mb. for every 30 ft. of ascent

Altimeters may be calibrated on either the Isothermal or the I.C.A.N. assumption. Nowadays the I.C.A.N. law is usually assumed. But whatever assumption is made in calibrating the instrument, height will seldom be correctly indicated. And that for two reasons. First, the pressure at sea level is not always 1013·2 mb. That is merely an average figure. Secondly, temperature varies, and the reading of the altimeter is affected by the temperature prevailing at various heights.

There are rules for correcting altimeter readings for temperature, but in practice the correction is always found by means of a specially constructed circular slide rule called a " Height and Air-speed Computer."

The method of allowing for changes in sea-level or ground-

level atmospheric pressure will be understood from the examples worked below. The student needs to bear in mind that the altimeter is an instrument which measures pressure but records the measurements in feet. Every height reading on the instrument is associated with a definite pressure, and whenever the instrument is subjected to that pressure it will indicate that height. Thus, suppose we set the altimeter
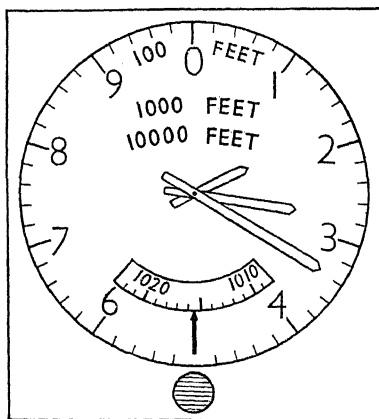

FIG. 71

so that the pointer indicates the height (say 450 ft.) of the aerodrome above sea level. Suppose that at that time the pressure at the aerodrome is 997 mb. Then *whenever the altimeter is subject to pressure 997 mb. it will read 450 ft.* Alternatively, we could set the instrument to read zero at the aerodrome. In that case the instrument will read zero whenever the pressure is 997 mb.

In the type of instrument known as a " Sensitive Altimeter " a barometric (pressure) scale is provided (Fig. 71). Any pressure may be set, by turning a knob, on the pressure scale, and the instrument will read zero height whenever the pressure is that set on the pressure scale. Thus if, on

approaching an aerodrome, we are informed that the ground-level pressure at that aerodrome is 1,015 mb., and we set the pressure scale to 1,015 mb., we know that the altimeter will read zero when we land at the aerodrome.

Example 1: Aerodrome A is at sea level. Pressure there is 1,009 mb. The altimeter is set to read 0. What will the instrument read on landing at aerodrome B, where the ground-level pressure is 997 mb. ?

Pressure 1,009 mb. gives reading, 0 ft.

Pressure 997 mb., being 12 mb. less than 1,009 mb., will give a reading $0 + 12 \times 30 = 360$ ft.

On landing at B the altimeter will read 360 ft. B may or may not be 360 ft. above sea level. If the sea-level pressure at B is 1,009 mb., as it was at A, then B is 360 ft. above sea level. The important thing for the navigator to know is what his altimeter will read when he lands at B.

Example 2: Aerodrome P is 350 ft. above sea level.

Ground pressure at P is 1,002 mb. Altimeter set to read 350.

Aerodrome Q is 200 ft. above sea level and ground pressure at Q is 998 mb.

What will the altimeter read on landing at Q?

At 1,002 mb., instrument reads 350 ft.
At 998 mb., instrument reads $350 + (1002 - 998) \times 30$ ft.
$$= 470 \text{ ft.}$$

The altimeter will read 470 ft. on landing at Q.

Notice that, whereas the altimeter was reading correctly at P, at Q it is overreading by 270 ft., since it reads 470 ft. at the ground level, which is only 200 ft. above sea level. An altimeter which is overreading may be a source of much danger, and before concluding our account of the altimeter we will consider the circumstances in which overreading is likely to arise.

(321)

9

Distribution of Atmospheric Pressure

The geographical distribution of atmospheric pressure is shown on weather charts by means of lines of equal pressure (at mean sea level), known as Isobars (Fig. 72). The kind of distribution shown in Fig. 72, where we have a region
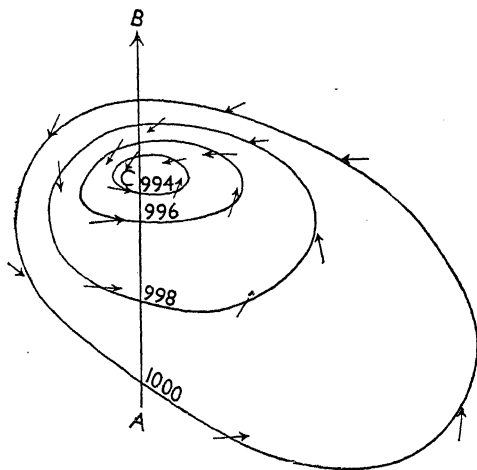

Fig. 72

of relatively low pressure, is called a " depression " or a " low."

Wind direction is shown by the arrows. If the student will examine any weather chart he will find that the winds, as in Fig. 72, blow nearly parallel to the isobars but slightly inclined towards the area of relatively low pressure.* The wind therefore circles round a region of relatively low pressure, and in the northern hemisphere the direction of circling is anti-clockwise. The law known as *Buys Ballot's Law* states :

---

* The winds shown on the chart are those at the surface of the Earth. As you ascend you find the direction of the wind changing. At 1500 feet the wind, in general, blows almost exactly along the isobars.

" If you stand with your back to the wind, the area of relatively low pressure will be on your left if you are in the northern hemisphere, and on your right if you are in the southern hemisphere."

Now suppose an aircraft flies across the depression shown in Fig. 72, travelling along the arrow AB. As long as the centre of the depression lies ahead, the wind will clearly be on the port side of the aircraft, while when the centre of the depression has been passed, the wind will be on the starboard side.

In general, in the northern hemisphere, if the wind is on the port side, we are flying towards a region of relatively low pressure—that is, if there is starboard drift we are approaching a low.

Now consider the effect upon the altimeter of flying from a region of higher to one of lower pressure. The effect of a fall of pressure is always to make an altimeter register an increase in height. Hence, as the aircraft flies towards a region of relatively low pressure, the altimeter will register an increase of height, although no such increase has taken place. Suppose, for instance, that both A and C are at sea level (Fig. 72), and that at ground level at A the altimeter correctly reads 0 ft. If the aircraft lands at C, where the pressure is 994 mb., as against the 1,000 mb. at A, the altimeter at ground (sea) level at C will read (1000 — 994) × 30 ft. = 180 ft. At or above C, then, the altimeter is overreading by 180 ft. The effect of flying into a region of relatively low pressure is to make the altimeter overread. If the wind remains on the port side for any length of time we should expect our altimeter to be overreading.

Another way, of much practical significance, of regarding the matter is as follows. Suppose that before taking off from an aerodrome, A, the altimeter is set to read the height of A above sea-level. Then, *at any place where the sea-level pressure* ·

is equal to the sea-level pressure at A, the altimeter will correctly indicate height above sea level. We decide to fly at, say, 2,000 ft. The only way of doing that is to keep the aircraft at such a level that the altimeter reading is constant, viz. 2,000 ft. But if we fly to a region where the sea-level pressure is less than that at A the altimeter will overread. We think we are still at the 2,000 ft. indicated by the altimeter, but 2,000 ft. on the altimeter now means only, perhaps, 1,700 ft. above sea level. We thought we should clear a range of hills, 1,700 ft. high, by 300 ft. Instead of clearing them, we hit them !

EXERCISE IX B

1. At aerodrome A, 150 ft. above sea level, ground pressure was 997 mb. Altimeter set to read 150 ft.

Approaching aerodrome B you are informed that the ground pressure there is 993 mb. What will your altimeter read on landing at B ?

2. At aerodrome C, ground pressure 1,001 mb., you set your altimeter to zero. What will the instrument read on landing at D, where the ground pressure is 998 mb. ?

3. Leaving aerodrome E, which is 400 ft. above sea level, you set your altimeter to read 400 ft. The sea-level pressure at E is 1,013 mb. What will the altimeter read on landing at F, which is 550 ft. above sea level, if the sea-level pressure at F is 1,011 mb. ?

4.* Using a Height and Air-speed Computer, find the true heights corresponding to the indicated heights in the following cases :

Temperature (°C) . .	20	30	−10	−30
Indicated height (ft.) . .	5,560	8,000	10,000	8,500
True height (ft.) . . .				

5.* Compare the results found in Question 4 with those obtained from the formula :

True height = Indicated height × (·964 + ·0036 t), where t is temperature Centigrade.

6.* If the specific gravity of mercury is 13·6, find the weight of a column of mercury 760 mm. long and cross-section 1 square cm. If there are 981 dynes in 1 gramme's weight, calculate the pressure in mb. corresponding to 760 mm. of mercury.

AIR-SPEED INDICATOR

Measurement of Air-speed : the Pitot Tube

By " air-speed " is meant speed *through* the air. It has no connection with wind, which is a movement *of* the air relative to the Earth. The principle employed in the measurement of air speed was used by Pitot in the eighteenth century for measuring the speed of rivers.

Suppose a tube closed at one end is placed with the open end facing a stream of air ; or, what amounts to the same thing, suppose the tube moved through air with the open end facing the direction of motion. Then it is easy to see that pressure will be built up in the tube, and the greater the velocity of the tube through the air the greater the pressure that will be built up. This is the principle of the airspeed indicator, of which Fig. 73 is a diagrammatic picture.

The Pitot tube (see Fig. 70) is connected to a capsule, F, in the air-speed indicator, a metal capsule of the kind used in the altimeter (Fig. 73). The effect of the aircraft's motion through the air is to build up a pressure inside the capsule, and expansions of the capsule due to such pressure are magnified and communicated through a mechanism diagrammatically represented in Fig. 73 by the rods G to the pointer on the dial of the instrument. Actually, as in the altimeter, the plane of the dial is perpendicular to the axis of the capsule. A tube connects the inside of the case ABCD to the
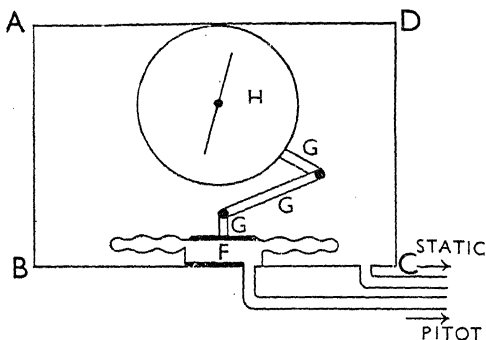
FIG. 73

static head, since it is the difference between the pressure in the Pitot tube and the static pressure at the position of the aircraft that is determined by the air-speed.

Correction of Indicated Air-speed

The reading of the air-speed indicator is called the Indicated Air-Speed (I.A.S.). To obtain the True Air-Speed (T.A.S.) from the I.A.S. various corrections have to be applied.

(i) Position Error. This is due to the eddies in the neighbourhood of the aircraft, the effect of which cannot be entirely eliminated by suitable placing of the pressure head on the aircraft. Position error varies with speed and has to be tabulated for each type of aircraft. When position error has been applied to the I.A.S. the result is called the Corrected Air-Speed (C.A.S.).

(ii) Density Error. The difference of pressure between the inside and the outside of the capsule in the air-speed indicator is given by the formula

$$p = \tfrac{1}{2}\rho V^2$$

where ρ is the density of the air and V the air-speed.

Now, the density of the air will decrease with height and is also affected by temperature. To obtain the T.A.S. from the C.A.S. we have, therefore, to apply a correction for height and temperature. The amount of this correction may be found by means of the Height and Speed Computer, to which reference has already been made in connection with the altimeter.

Alternatively the following formula may be used to give the amount of the correction for height :

To C.A.S. add 1·75 per cent. of C.A.S. for every 1,000 ft. of height above sea level.* Thus :

$$\text{T.A.S.} = \text{C.A.S.} \ (1 + \cdot0175 \ h),$$

where h is the number of thousands of feet of height.

Example : Height 20,000 feet. I.A.S. = 180 k.

$$
\begin{array}{rl}
\text{Instrument and Position Error} \dagger = & + 3 \\
\text{C.A.S.} = & \overline{183 \text{ k.}} \\
1 \% \text{ of C.A.S.} = & 1\cdot83 \\
\tfrac{1}{2} \% \text{ of C.A.S.} = & 0\cdot915 \\
\tfrac{1}{4} \% \text{ of C.A.S.} = & 0\cdot457 \\
\therefore 1\cdot75 \% \text{ of C.A.S.} = & \overline{3\cdot202} \\
\text{For ht. 20,000 ft.} & \times 20 \\
& \overline{64\cdot040 \text{ k.}}
\end{array}
$$

$$
\begin{array}{lll}
\text{C.A.S.} & 183 & \text{k.} \\
\text{T.A.S.} & 247 & \text{k.}
\end{array}
$$

* The fact that, at a height, the C.A.S. will be *less* than the T.A.S., so that the 1.75 per cent. of C.A.S. has to be *added*, can be inferred from the formula $p = \tfrac{1}{2}\rho V^2$ or from commonsense as follows : The greater the height, the thinner the air ; the thinner the air, the less the pressure that will be built up, for a given air-speed, in the air-speed indicator capsule ; and the less that pressure is, the lower will be the indicated air-speed.

† It is usual to combine Position Error with any errors due to faults in the instrument.

EXERCISE IX C

1. Your true height is 4,000 ft. Find the T.A.S. if the C.A.S. is 100 m.p.h.

2. If you want to fly at a T.A.S. of 165 k. at height 12,000 ft., what should be your C.A.S. ?

3. Copy and complete :

C.A.S. . .	180 k.	180 k.	200 m.p.h.	200 m.p.h.	225 k.
Height (ft.) .	3,000	10,000	8,000	15,000	18,000
T.A.S. . .					

4. Copy and complete :

I.A.S. . . .	250 m.p.h.	280 m.p.h.	150 k.	180 k.
Posn. and Instr. Error	−5	+3	−2	+2
C.A.S. . . .				
Height (ft.) . .	9,000	5,000	2,500	7,500
T.A.S. . . .				

5. At aerodrome A, 500 ft. above sea level, the ground pressure is 996 mb. The altimeter is set to read 500 ft. In course of flight over aerodrome B, 150 ft. above sea level, where ground pressure is 1,001 mb., the air-speed indicator reads 185 m.p.h. Instrument and position error + 4. The altimeter reads 2,500 ft. Find the T.A.S.

CHAPTER X

* ASTRONAVIGATION

Landmarks and Skymarks

SUPPOSE that, by means of a rangefinder, you measure the (horizontal) distance of your position from a lighthouse as 15 miles. If, then, you draw a circle of radius 15 miles on the chart, with the lighthouse as centre, your position will be somewhere on the circle. Whenever he knows the distance of a landmark, such as a lighthouse, the navigator can draw such a *position circle* on his chart.

It often happens (for example, on dark nights or when flying above cloud or fog) that landmarks are not visible to the navigator. He may then turn for help to skymarks— the Sun, Moon, planets, and stars. From observations of such bodies it is possible to obtain position circles. A brief outline of the method is given in this chapter.

Substellar Points and Altitude

Since the Earth is a sphere there is, at any given time, a point on the Earth's surface which is directly beneath any particular heavenly body. Thus, at any given moment, there is one point on the Earth's surface where the Sun is directly overhead, another where the Moon is overhead, and another where (say) the star Arcturus is overhead. These points are called the *substellar points* of the Sun, Moon, and Arcturus respectively.

The substellar point of a heavenly body is the point where the line joining the Earth's centre to the body cuts the Earth's surface.

* See Note on page xi.

In Fig. 74, O is the position of an observer and S is the substellar point of a heavenly body X. (The circle in the figure is the great circle joining O to S, since the centre of the circle is the centre of the Earth.) The horizontal at the
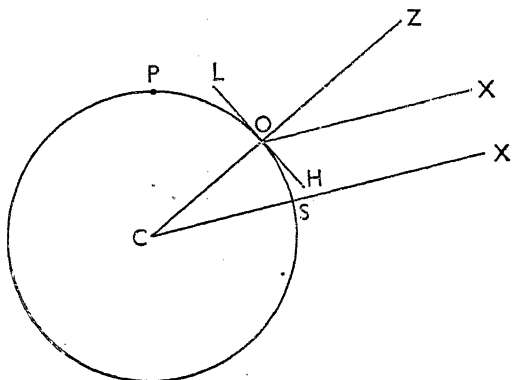
FIG. 74

observer's position is given by the tangent HL. The *altitude* of X at O is the (acute) angle HOX between the horizontal and the direction of the heavenly body. It is the angle through which the observer must raise his line of sight from the horizontal in order to be looking directly at X. This angle is measured by means of an instrument called a Bubble Sextant. As will be seen from what follows, this measurement of an altitude in astronavigation corresponds to the measurement of the distance of the lighthouse in our illustration above:

Now, the stars are at enormous distances from the Earth. Hence the line joining the centre of the Earth, C, to X will be parallel to OX.* Since OX is parallel to CX,

---

* This is not true for the Sun or Moon, which are much nearer than the stars to the Earth. In this chapter we shall deal only with observations of stars.

$$\text{angle ZOX} = \text{angle ZCS}$$

$$= \text{angle OCS}$$

Now,   angle ZOX $= 90° -$ angle HOX

$$= 90° - \text{altitude of X}$$

Hence,   angle OCS $= 90° -$ altitude of X

But, angle OCS measures the great-circle distance of the observer from the substellar point S. If we call this the " arc-distance " we have shown that

Arc-distance of substellar point$=90°-$altitude of star . (1)

Position circle and position line : Suppose that the altitude of a star is found to be 65°. Then by equation (1) the arc-distance of the observer from the substellar point is $90° - 65°= 25°$. The distance in nautical miles is 25×60, that is, 1,500. We know, then, that the observer lies on a "small circle" drawn with the substellar point, S, as centre, and of radius 25° or 1,500 nautical miles (Fig. 75). Every observation of the altitude of a star gives such a position circle.
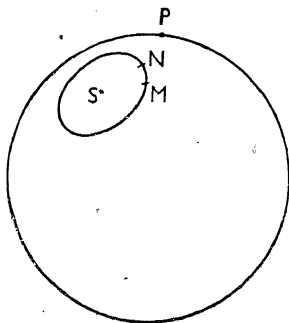
FIG. 75

The altitudes used in practice range from about 20° to 80°. The corresponding range of arc-distance of the substellar point is from 70° to 10°, that is, from 4,200 n.m. to 600 n.m. The radius of the position circle will, therefore, always be large, usually between 2,000 n.m. and 4,000 n.m. From this, two things follow. First, the substellar point will be too far away to appear on the chart you are using for your flight, so that you cannot draw a circle on the chart with the

substellar point as centre.*   Secondly, you are concerned only with a small part of the position circle in the neighbourhood of the aircraft's position, and, since the radius of the circle is so large, the small part in which you are interested (say MN in Fig. 75) may be regarded as a straight line. This straight line is called an astro-position line.

Plotting the astro-position line :   A point **A,** called the " Assumed Position," near the D.R. position is selected. For reasons which need not be mentioned here we select A so that it has an exact number of degrees in its latitude, and so that the Ch. Long. between it and the substellar point S is also an exact number of degrees.
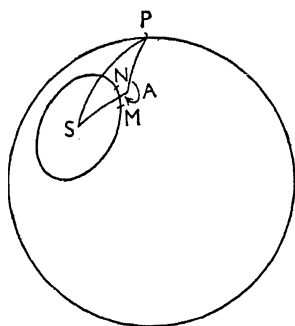
Join A to S and to the pole, P, by great-circle arcs (Fig. 76). Also join S to P by a great-circle arc. A triangle such as APS, whose sides are great-circle arcs, is called a S p h e r i c a l   T r i a n g l e.   The " sides " of a spherical triangle (PA, AS, and SP in Fig. 76) being

FIG. 76

great-circle arcs, may be measured by the angles they subtend at the centre of the Earth. The " angles " of the triangle are the angles at which the sides cut one another. Thus, in the spherical triangle APS in Fig. 76 the angle APS is the angle at which the arcs AP and SP cut at P. It is also the angle between the planes of the arcs AP and SP.

* Note that even if the whole of the " position circle " could be drawn on the chart it would not be a *circle*. A small circle on the Earth's surface is represented by a non-circular curve on the Mercator chart. Only when the observer is near the Equator and the altitude of the observed body is very large can the position circle be drawn as a circle on the chart. But whatever the shape of the curve on the chart the part near the observer, with which alone he is concerned, will be appreciably straight.

Now, if we know the lengths of two sides, such as PA and PS in the triangle APS, and know also the angle (APS) between them, the length of the third side (SA) can be found by calculation. It is also possible to calculate the remaining angles, SAP and ASP, of the triangle. There is nowadays no need for the air navigator to know how these calculations are performed, since they have been worked out for a very large number of triangles, the results being published in Navigation Tables.

Let us suppose that the navigator has chosen his Assumed Position, A, and that he has worked out (by the methods described in the section on the *Air Almanac* below) the position of S. Knowing the positions of these two points, he consults his Navigation Tables and finds (say) :

(i) the arc-distance AS = 52° 35′

(ii) the "Azimuth" of S (that is, the bearing of S from A, the angle shown by the curved arrow in Fig. 76) = 260°.

On the chart he draws a line, AB (Fig. 77) running in the direction 260°. If produced far enough, this line (*i.e.* the great circle represented by the line) would pass through the substellar point S.
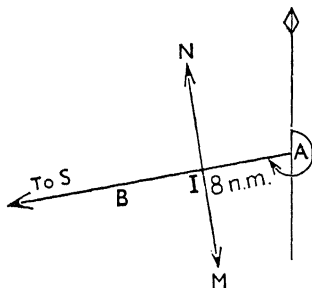
By means of his sextant the navigator has found that the altitude of the star was 37° 33′. Then, by equation (1), the radius of the position circle is 90° − 37° 33′ = 52° 27′. Thus, if the position circle cuts AB at I (see Figs. 76 and 77),

FIG. 77.

I is distant 52° 27′ from S

A is distant 52° 35′ from S

Hence, AI is 8′, that is, 8 nautical miles.

So, to draw the astro-position line the navigator sets off

8 n.m. along AB from A (AI is called the " Intercept ") and draws MN through I at right angles to AI. MN is the position line.

If the *observed* arc-distance SI were greater than the *calculated* (or " assumed ") arc-distance SA, MN would be drawn on the side of A remote from S. Thus, if the azimuth of S were 260°, the observed arc-distance 52° 45', and the assumed arc-distance 52° 35' we should draw the position line as in Fig. 78.
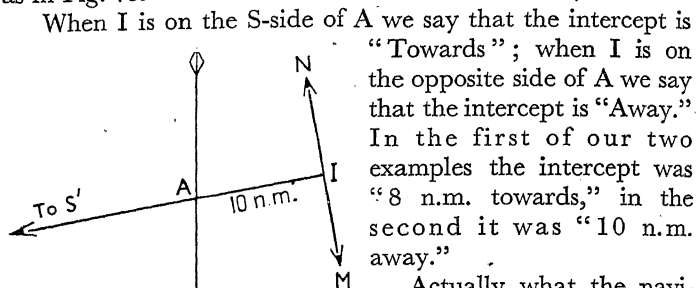
When I is on the S-side of A we say that the intercept is "Towards"; when I is on the opposite side of A we say that the intercept is "Away." In the first of our two examples the intercept was " 8 n.m. towards," in the second it was " 10 n.m. away."

FIG. 78

Actually what the navigator takes out of his Navigation Tables is not the assumed arc-distance SA but the corresponding altitude, 90° — AS. We may call this the "Assumed altitude." To find the intercept he then compares the assumed altitude with the observed altitude :

> If observed altitude is greater than assumed altitude, the intercept is " towards " ;
>
> if observed altitude is less than assumed altitude, the intercept is " away."

We have seen that in order to find the assumed altitude and the azimuth from Navigation Tables we must know the following parts of the triangle APS :

> (i) The side PA. This is the " complement " of the latitude of A, that is to say, 90° — latitude of A. Actually this subtraction has been performed by the

compilers of the tables so that the navigator finds the information he needs tabulated under various latitudes, and consults the table belonging to the latitude, not to the complement of the latitude, of A.

(ii) The side PS. This depends upon the latitude of S which is found, as described in the next section, from the *Air Almanac*.

(iii) The angle APS. This also is found in the *Air Almanac*.

What is the *Air Almanac* and how can we obtain from it the information we need ?

The Air Almanac

The *Air Almanac* is a kind of time-table of heavenly bodies. It gives us the position of the substellar point for the Sun, Moon, planets, and stars at various times. Whenever a " sight " is taken—that is, whenever the navigator measures the altitude of a heavenly body—the time of the observation is carefully noted. For this purpose an accurate watch is used. The watch does not show the local time of the part of the world in which the navigator happens to be, but *Greenwich Mean Time* (G.M.T.), namely, the time kept by clocks at Greenwich (and, for that matter, all over the British Isles).

At Greenwich Observatory elaborate observations of heavenly bodies have been made over many years. From these observations it is possible to calculate what the position of the substellar point of any heavenly body will be at any moment of G.M.T. in the future. These forecasts are published in the *Air Almanac*.

The latitude of the substellar point of a heavenly body is called the body's *declination*. The declination of a *star* changes very slightly and slowly, and to take the declination of a star out of the *Air Almanac* we do not need to know the G.M.T. To all intents and purposes we may regard the

declination of a star as constant.* Hence, as the Earth rotates on its axis the substellar point of a star moves from East to West along a parallel of latitude, namely, the latitude which is equal to the declination of the star.

The declination of bodies, such as the Sun, Moon, and planets, which are, compared with the stars, near the Earth, changes quickly. Accordingly the declination of these is given in the *Air Almanac* at close time-intervals. To get the declination of the Sun, for example, accurately enough for navigational purposes we need to know the G.M.T. to the nearest second.

The longitude of the substellar point is harder than the latitude to find. What is wanted is the Ch. Long. between the observer's meridian and the meridian of the substellar point. This is called the star's *hour angle*. It is important that the student should understand what an Hour Angle is, and we shall consider the matter in a separate section.

Hour Angles

The Hour Angle (H.A.) of a heavenly body is the *westward* change of longitude from a given meridian to the meridian of the body's substellar point.

If the given meridian is that of Greenwich the H.A. is called the Greenwich Hour Angle (G.H.A.).

If the given meridian is that of the observer, the H.A. is called the Local Hour Angle (L.H.A.).

---

* The reason for this is as follows : The stars are at such immense distances from the Earth that they would have to move enormous distances for their directions from the Earth to change noticeably. Hence their directions are almost constant. Moreover, the Earth's axis points in a nearly constant direction. Hence the angle between the Earth's axis and the direction of any star is practically constant, and as that angle is the complement of the star's declination, it follows that the declination must be almost constant. This does not hold for heavenly bodies which are nearer than the stars to the Earth, namely, the Sun, Moon, and planets.

In Fig. 79 PGK is the meridian of Greenwich, PAL the meridian of the observer (or rather of his "Assumed Position"), and PSM the meridian of the substellar point.

The G.H.A. of the star is the angle GPS, or the arc KM of the Equator. The L.H.A. is the angle APS, or the arc LM. The difference between these two angles is the angle GPA, which is the (West) longitude of A. So that:
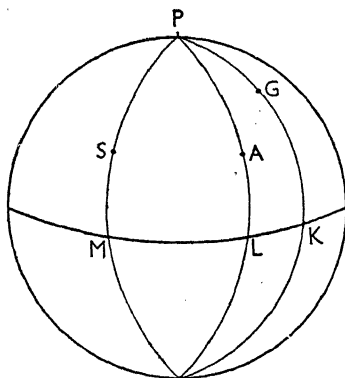

FIG. 79

$$\text{L.H.A.} = \text{G.H.A.} - \text{West Longitude (of A)} \qquad . (2)$$

If the longitude of A were East, so that S and A were on opposite sides of the Greenwich meridian, we should have

$$\text{L.H.A.} = \text{G.H.A.} + \text{East Longitude (of A)} \qquad . (3)$$

In the *Air Almanac* the G.H.A. of the Sun, Moon, and planets is tabulated against G.M.T. Knowing the G.M.T. from our watch-reading at the time of the observation, we can at once look up the G.H.A. of the observed body for that time, and so by means of equation (2) or (3) find the L.H.A. This L.H.A. is the angle APS, which, as we saw in the previous section but one, we need to know before we can get the information we require from our Navigation Tables.

For *stars* the L.H.A. is found in a different way. There is a point in the heavens called the First Point of Aries. It is the position of the Sun at the moment when it crosses the Equator from South to North in March. Hence the substellar point of the First Point of Aries is always on the Equator.
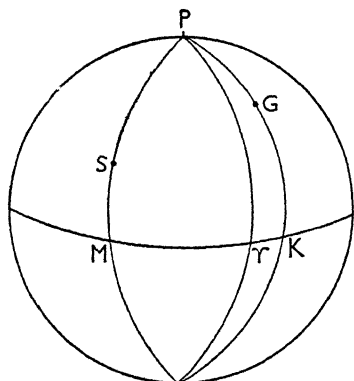
FIG. 80

The symbol for the First Point of Aries is ♈. In the *Air Almanac* the G.H.A. of ♈ is tabulated against G.M.T.

The H.A. of a star measured from the meridian of ♈ is called the star's Sidereal Hour Angle (S.H.A.). The S.H.A.'s of the stars commonly used in navigation are tabulated in the *Air Almanac*. Knowing the G.H.A. of ♈ and the S.H.A. of a star, we can calculate the G.H.A. of the star as follows:

In Fig. 80, S is the substellar point of a star, ✳.

G.H.A. of ♈ = arc K♈

S.H.A. of ✳ = arc ♈M

G.H.A. of ✳ = arc KM

= arc K♈ + arc ♈M

So   G.H.A.✳ = G.H.A.♈ + S.H.A.✳   .   . (4)

Having found the G.H.A. of ✳ we apply the longitude of our assumed position by means of equation (2) or (3), and so find the L.H.A. of ✳. We find that

$$\text{L.H.A.✳} = \text{G.H.A.♈} + \text{S.H.A.✳} \left. \begin{array}{l} + \text{ E.} \\ - \text{ W.} \end{array} \right\} \begin{array}{l} \text{Longitude} \\ \text{of A} \end{array} \quad . \quad . (5)$$

Example: In D.R. position 30° 53′ N., 69° 15′ E. at G.M.T. 18 h. 31 m. 20 s. on 9th April, 1942, the altitude of Regulus was 54° 22′.

From the *Air Almanac* we find:

S.H.A. of Regulus   = 208° 41′

Declination of Regulus =   12° 15′ N.

From the *Almanac* also we find :

G.H.A. ♈ for G.M.T. 18 h. 31 m. 20 s. on 9th April = 115° 12′.

We can now calculate the L.H.A. of Regulus by means of Equation (5). Note that as Assumed longitude we choose 69° 07′ E., since that is the nearest longitude to our D.R. longitude 69° 15′ E., which will make the L.H.A. an exact number of degrees.

G.H.A. ♈	115° 12′
S.H.A. ✶	208° 41′
G.H.A. ✶	323° 53′
Longitude E.	69° 07′
L.H.A. ✶	393° 00′
	— 360°
L.H.A. ✶	33° 00′

As Assumed latitude we take 31° N.

We now have the following data with which to enter our Navigation Tables :

Latitude 31° N, Declination 12° 15′ N, Hour Angle 33°.

Using these data we find from the Navigation Tables that :

Altitude = 54° 16′, Azimuth = 294°.

The Intercept can now be found :

Assumed altitude = 54° 16′
Observed altitude = 54° 22′
Intercept = 6′ towards

The method of plotting the position line is shown in Fig. 81.

If two stars on different bearings are observed simultaneously we get two position lines, of which the intersection

N   69°07′E

I

6 n. m.

31°N ·

29°40°   +D
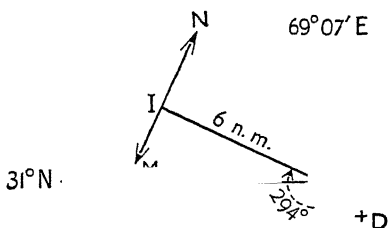
FIG. 81

is a fix.   If the two stars are not observed at the same time the method of the Running Fix (see Chapter VI) must be used.

The Pole Star : We saw in the section on Substellar Points and Altitude (page 139) that

Arc-distance of substellar point = 90° — altitude of star.

It follows that

Altitude of star = 90° — arc-distance of substellar point.

Now if the star were exactly overhead at one of the Earth's poles, so that the pole was the substellar point, we should have :

Altitude of star = 90° — arc-distance of pole from observer
                 = latitude of observer

Thus, if there were a star exactly above the North Pole its altitude from any place would be equal to the North latitude of the place.

The star Polaris, commonly known as the Pole Star, has a substellar point very near to the North Pole. The declination of Polaris is about 88° 59'. The substellar point of the star therefore moves round the pole in a small circle of radius 61 n.m.

Clearly the altitude of Polaris will not be equal to the observer's latitude, but it will differ from the latitude by a small amount. That amount is tabulated, so that, knowing the time of our observation, we can find in the table the correction to apply to the altitude. Actually the correction is tabulated against the L.H.A. ♈, which we have seen above how to calculate. The correction is called the Q correction.

Suppose the altitude of Polaris is found to be 52° 13', and that the Q correction for the L.H.A. ♈ of the time of the observation is + 42'. Then :

$$\text{Latitude of observer} = 52° \ 13' + 42'$$
$$= 52° \ 55' \ \text{N}.$$

There is no corresponding method of finding latitude in the Southern Hemisphere, since no star has its substellar point in the immediate neighbourhood of the South Pole.

CHAPTER XI

* RADIONAVIGATION

Introductory : There is no doubt that wireless signals, already of great value in air navigation, will become of rapidly increasing importance as aviation develops. The fixing of the position of aircraft during long flights, such as will be of daily occurrence in the near future, is likely to be effected to a considerable extent by means of wireless.

Progress in radionavigation will be along two lines : radiotechnological and navigational. On the one hand, there will be improvement in the apparatus used for reception of directional wireless signals, a matter which is not the immediate concern of the navigator. On the other hand, the study of direction between places far apart (such as a wireless transmitting station and an aircraft), including the representation on charts of the information obtained from wireless directional signals, is a part of navigation in which we may expect further developments. Of this second, purely navigational, aspect of wireless direction-finding an elementary description is given in this chapter.

Direction of Wireless Signals

When a stone is dropped into still water, waves spread out in circles from the point where the stone strikes the water. In a similar way, when a wireless installation is transmitting, electric impulses spread over the Earth's surface in expanding small circles from the position of the transmitter. Just as, in the case of the stone dropped on to a sheet of water, the circular waves expand along straight lines (namely, the radii of the circles), so wireless waves expand along great-circle arcs

* See note on page xi.

which radiate from the transmitter and cut the small circles at right angles.

Now suppose an aircraft, A, is receiving signals from a distant transmitter, S (Fig. 82). The impulses spread from S in the small circles shown by dotted lines. The impulses move along the great-circle arcs as shown by the radiating arrows. As they pass A the impulses will appear to travel
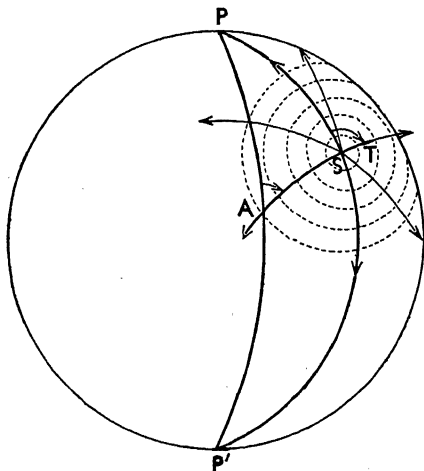

FIG. 82

in the direction SA, where SA is the great-circle arc joining S to A. By means of a special apparatus, called a " Loop Aerial," the wireless operator in the aircraft can tell from what direction the signals are coming. That is to say, he can measure the true bearing (namely, the angle PAS) of S from A. This information he passes to the navigator, who uses it to draw a position line on his chart in the manner described in a later section of this chapter.

Alternatively, the aircraft may transmit signals to S. These would spread out from the position of the aircraft in small circles, not shown in Fig. 82, and would reach S along

the great-circle arc AS. An observer at the station deter-
mines with his apparatus the direction from which he is
receiving signals from A. In other words, he measures the
true bearing of A from S. He sends a message to the navigator
of the aircraft telling him the true bearing of the aircraft
from the station, and the navigator can then draw, by methods
described below, a position line on his chart.

Directions on Maps : Convergency

We have seen that the bearings obtained from wireless
signals are great-circle bearings. Strictly speaking, this applies
to all true bearings, including the visual bearings obtained by
correcting a compass-bearing for variation and deviation.
But in the case of visual bearings the observed object is so
near to the aircraft that there is no appreciable difference
between the great-circle bearing and the rhumb-line bearing,
so that we can draw the line of bearing immediately on
the chart as a straight line in the manner described in
Chapter VI.

The drawing of position lines from wireless bearings is not
so simple a matter as for visual bearings, for in laying off
wireless bearings on a chart it is usually not possible to ignore
the difference between the rhumb-line and the great-circle
bearing. The distance between the aircraft and the station
is generally considerable (say 100 miles or 200 miles), while
in the future we may expect wireless bearings over much
greater distances to be frequently taken. The navigational
theory of wireless direction-finding is concerned almost
entirely with the fact that the great-circle arc joining two
places is usually markedly different from the rhumb-line
joining them, when the places are far apart. We turn now
to consider this matter.

A great circle, other than the Equator or a meridian, cuts
all meridians at different angles. It is evident, for example,
that in Fig. 82 the angle PST is greater than the angle PAT.
This is due to the fact that the meridians converge towards

the pole. The difference, namely, angle PST — angle PAT, is called the *convergency* for the points A and S.

Suppose that the meridians, PA and PS, of Fig. 82 are represented on a topographical map by KL and MN in Fig. 83. On the topographical maps commonly used in air navigation the meridians are represented by straight lines converging towards the nearer pole, while other great circles are, with a high degree of accuracy, also represented by straight lines. Moreover, angles on the Earth's surface are correctly reproduced on the map, so that the angle PST of Fig. 82 will be represented by an equal angle PST in Fig. 83, and similarly with angle PAT in both figures. Let the number of degrees in angle PST be X,

Fig. 83

and in angle PAT be Y. The angle between the meridians we will call Z. Then,

Convergency = X — Y

= Z, since X is the external angle, opposite to A and P, of triangle PAS.

Thus, on the map (and the same is approximately true on the Earth's surface) the convergency is the angle of inclination of the meridians, at A and S, to one another. The convergency is zero if A and S are on or near the Equator, while at or near the pole it is equal to the Ch. Long. between the meridians. A formula which is accurate enough for all practical purposes is :

Convergency = Ch. Long. × sin Mean Lat.

Suppose A is the point 48° 13′ N., 6° 00′ W. (near the south-west corner of Chart A), and S is the Wireless Station
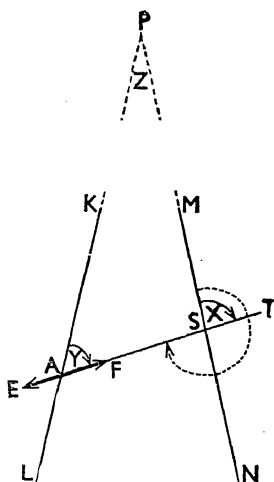
at Cherbourg (49° 37′ N., 1° 35′ W.). We find the convergency for A and S as follows :

	49° 37′ N.	1° 35′ W.
	48° 13′ N.	6° 00′ W.
2) 97° 50′		Ch. Long. 4° 25′ W.
Mean Lat. 48° 55′ N.		

Then, ． Convergency = 4° 25′ × sin 48° 55′
= 3° 18′.

In practice, the convergency is found by means of a diagram provided with charts. From this diagram, knowing the Mean Latitude and the Ch. Long. we can read off the convergency immediately.
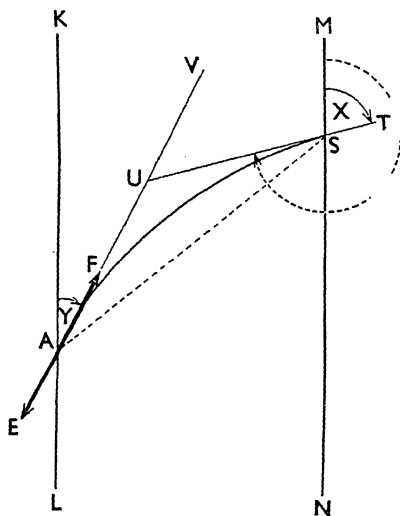

FIG. 84

Now suppose that Fig. 84 represents, on a Mercator chart, the same meridians as those in Fig. 83. Here the great-circle arc from A to S is represented by a curve which, for all practical purposes, may be regarded as the arc of a circle. The direction of the great-circle arc at A is the angle KAU between A's meridian and the tangent AU to the arc at A, while the direction at S is given by angle MST, ST being the tangent at S.

It is easy to see that angle VUT = X − Y, since VUT is the angle by which the direction of the arc changes as we pass from A to S. Hence, Convergency = angle VUT.

Also, since UA and US are tangents,

$$\therefore \qquad UA = US$$

$$\therefore \text{ angle } UAS = \text{ angle } USA = \tfrac{1}{2} \text{ angle } VUT.$$

The angle (UAS or USA) between the great-circle arc and the rhumb-line (shown dotted in the figure) is called the *conversion angle*. So we have shown that

$$\text{Conversion Angle} = \tfrac{1}{2} \text{ Convergency.}$$

Let us now see how to apply these results to the drawing of wireless position lines.

When a Station takes the Bearing of an Aircraft

A navigator asks a wireless station to take a bearing of his aircraft. At the station the direction from which the aircraft's signals are received is observed and found to be, we will suppose, 250°. This bearing is signalled to the aircraft. What is the navigator to do with it ?

(*a*) *Using a Topographical Map :* Suppose (Fig. 83) that S is the station and KL the D.R. meridian of the aircraft. Through S draw SA which has bearing 250° at S (the 250° is shown by the curved, broken arrow). This represents the great circle along which the signals were received at S, and is therefore the position line on which the aircraft lies. It is necessary to draw only a part, EF, of the line, in the neighbourhood of the D.R. position.

(*b*) *Using a Mercator Map :* See Fig. 84. The station receives the signal along UT, the tangent to the great-circle arc at S.

From the latitude and longitude of the D.R. position and of S we find, as described above, the conversion angle. Suppose this is 2°. Then the direction of the rhumb-line, SA, will be 250° — 2° = 248°.

The navigator, therefore, draws, from S, a rhumb-line in direction 248°. Where this cuts the D.R. meridian, at A, he draws EF, making an angle of 2° with the rhumb-line AS.

Then EF will be a tangent to the great-circle arc at A. The position line will be a small part of the great circle near A, and we may take the line EF as the position line.

To fix his position the navigator must, of course, have a second position line. He may get this from an astro-observation or by asking a second transmitting station to take his bearing.

If there are two stations, S and S′, the navigator may ask S for his position. S takes the aircraft's bearing and asks S′ what the bearing is from S′. Then, at S, the two position lines are plotted. The position of the intersection of the two position lines is found and signalled to the navigator. This, when it is possible, is the best procedure, since it saves the navigator time and trouble, and the necessary plotting can be done in comfort at the station instead of under more difficult conditions in the aircraft.

When an Aircraft takes the Bearing of a Station

An aircraft is in D.R. position 48° 13′ N., 6° 00′ W. when the wireless operator takes a wireless bearing of Cherbourg, finding it to be 065°. How shall we draw the position line?

In the previous case, when a station took the bearing of an aircraft, we were able to lay off the line of bearing from the station whose position was known. But in the present case we do not know the position of the aircraft, at which the bearing is observed, so that a different procedure has to be followed.

If we were to plot on a Mercator map all the points from which S had the bearing 065° we should find that they lay on a curve, called a *curve of constant bearing*, which is shown by the line $A_1 A_2 A_3 A_4S$ in Fig. 85. Nearly enough for practical purposes, this curve, on a Mercator map, may be regarded as a circular arc equal to the great-circle arc ACS, but on the opposite side of the rhumb-line (which is the straight, dotted line).
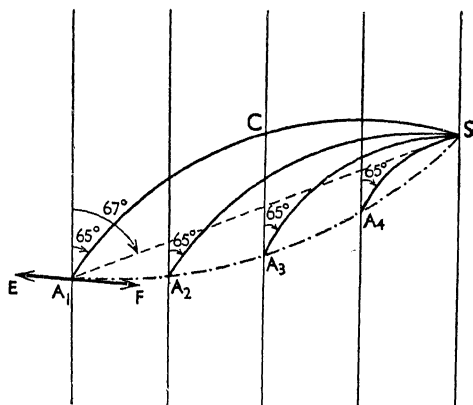
Fig. 85

The position line will be a small part of this curve of constant bearing in the neighbourhood of the D.R. position. The tangent to the curve of constant bearing at A will serve as the position line. The procedure for drawing the position line on a Mercator map is therefore as follows.

We find the Conversion Angle, as in the previous example. This is 2°. Hence (see Fig. 85) the rhumb-line bearing of S from A is 067°.* Accordingly, from S, we lay off the reciprocal (247°) of 067°. This is the straight line SA and gives the position of A on the D.R. meridian. Then, at A, draw EF, making an angle of 2° with AS, on the side of the rhumb-line opposite to the great-circle arc. EF is the required position line.

If we are using a topographical map (Fig. 86) we can draw through S a line K′L′ parallel to the D.R. meridian KL, then draw SA, making angle 65° with K′L′. At the point A, where this line (which represents the great-circle arc from S to A) cuts the D.R. meridian, draw EF, making an angle of

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* In the figure, of course, the conversion angle is greatly exaggerated for clarity.
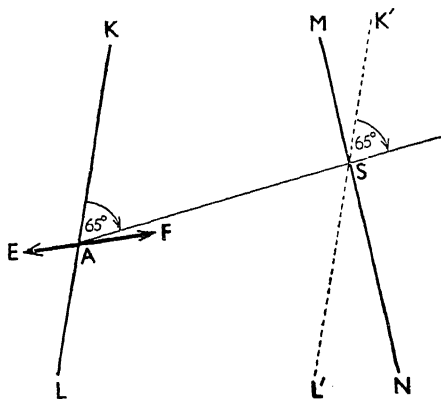
4° (the convergency) with AS. The reason for applying the full convergency here, instead of the conversion angle, will be evident from Fig. 85. Then, in Fig. 86, EF is our position line.

Degree of Accuracy

The methods of drawing wireless position lines just described are based upon certain approximations. They assume that both great circles and lines of constant bearing are represented on Mercator charts by circular arcs. When wireless bearings are taken over very great distances and the detection of directional signals reaches a high degree of accuracy these approximations may no longer serve. But with the degree of accuracy prevalent in air navigation at the present time, and with the comparatively short distances (usually less than 200 miles) over which wireless bearings are taken, the approximations are *more than* adequate. Indeed, conversion angles are often so small, in comparison with errors of directional detection or of steering, that navigators may sometimes neglect the conversion angle. In Fig. 84 or

Fig. 85, for example, sufficient accuracy will often be secured by regarding part of the *rhumb-line* near A as the position line ; or if, in Fig. 86, part of the great circle AS is taken to be the position line.

Reference has just been made to error of steering. This comes into the picture as follows. The bearing of a station is taken from an aircraft by means of a loop aerial. This is a circular aerial which can be rotated about an axis. When the plane of the loop is perpendicular to the direction along which the electric waves are travelling, the signals are at a minimum. By judging when the signals are weakest, the operator finds the direction of the signals *relative to the course of the aircraft.* In order, therefore, to get the true wireless bearing the relative bearing must be added to the true course, and if that course is not accurately read the wireless bearing will not be accurate.

We are concerned in this chapter only with the strictly navigational aspects of wireless bearings. But reference should be made to two sources of error which are of an electrical nature. The first is what is termed Quadrantal Error. This is due to the effect of the metallic structures of the aircraft upon incoming electric waves. The effect is to produce minimum signals when the loop is not quite perpendicular to the direction of the signal-impulses. The amount of the error depends upon the bearing of the signals relative to the aircraft's course, and is tabulated for the particular aircraft.

The second source of error in reception of signals is termed the Night Effect, because it is at a maximum at night. Waves from a transmitting station travel over the Earth's surface to the aircraft. But waves are radiated in all directions by the transmitter, and some go to the sky. The latter are reflected back to the Earth when they reach a region, some miles above the Earth's surface, called the Heaviside Layer, and, returning to the Earth, enter the loop aerial and modify the effect of the ground wave.

Beam Navigation

It will have been seen above that wireless bearings, though of great value to the air navigator, still leave him work to do in plotting his position lines and finding his fix. There is one use of wireless beams, however, which relieves the navigator of a great deal of work. I refer to the practice of flying along a wireless beam. There is no navigational theory attached to beam flying, so that only the briefest reference to the subject can be made in a book on air navigation.

An aircraft is to be flown to a certain place where there is a radio-transmitting station. The station emits a continuous stream of impulses. The aircraft carries apparatus so designed that, as long as the aircraft is heading in the direction from which the impulses are coming, that is to say, is heading for the station, a constant, high-pitched sound is heard in the wireless operator's telephones. If, on the other hand, the aircraft heads to one side of the beam, Morse dots are heard in the telephones, while if it heads to the other side of the beam, Morse dashes are heard. In this way it is possible to keep the aircraft heading for the station. The use of this homing device is obviously limited in war-time, when it is often necessary for a station to keep " wireless silence."

MISCELLANEOUS EXAMPLES

1. The latitude of LEICESTER is 52° 38′ N. and that of DONCASTER is 53° 31′ N. Both towns have the same longitude. Calculate the distance between the towns in (a) nautical miles, (b) statute miles.

2. Calculate the length of the Equator in (a) nautical miles, (b) statute miles.

3. Find the Ch. Lat. and Ch. Long. from CARDIFF to BREST. (A)

4. Find the Ch. Lat. and Ch. Long. from BLACKPOOL to MANNHEIM. (M)

5. Find the Ch. Lat. and Ch. Long. from 25° 04′ S., 179° 52′ W. to 13° 45′ N., 178° 14′ E.

B

1. Define : (a) Course, (b) Track, (c) Drift.

2. Copy and complete :

Course (T)	324°	145°	209°	175°		
Track (T)	327°	141°			265°	111°
Drift			11° P	5° S	12° S	10° P

3. Define a Rhumb Line. If you continued sufficiently far on any rhumb line (other than a parallel of latitude) at what point on the Earth's surface would you arrive ?

4. Define (a) Magnetic Meridian, (b) Variation, (c) Deviation.

5. Copy and complete :

True Co.	028°			148°	247°	004°
Magnetic Co.	036°	212°	333°		160°	
Compass Co.		216°		000° 157°	259°	355°
Variation		11°	10°	12°		18°
Deviation	5° E.			4° E.	2° W.	4° W

6. An object bears 158° T. Its bearing by Observer's Compass is 171° C. By Pilot's Compass the aircraft's course is 313° C, and by Observer's Compass the course is 312° C. If the variation is 10° W., find the deviation of each compass.

7. Copy and complete :

True Tr. .	184°		209°	018°
Drift . .	9° P	8° S.		12° P
True Co. .			215°	
Var. . .	12° W.	8° E.		10° W.
Mag. Co. .		310°	224°	
Dev. . .	3° E.	2° W.		5° W.
Comp. Co.			221°	

C

1. What is a graticule ? Describe the graticule of (a) a modified polyconic projection, (b) a Mercator projection.

2. Show by a sketch how the great-circle path between two places of the same latitude would appear on a Mercator chart.

3. Express the R.F. 1/100,000 in miles to an inch. Answer to three significant figures.

4. Define Meridional Parts.

5. Use meridional parts to calculate the rhumb-line track from ABINGDON (51° 40′ N., 1° 15′ W.) to MILAN (45° 28′ N., 9° 11′ E.).

6. Why are topographical maps unsuitable for plotting a long track-line ?

D

1. At 1135 hrs. an aircraft passes over WINCHESTER steering 277° C with T.A.S. 165 k. At 1223 hrs. the aircraft passes over BUDE. Find the drift and the W/V.

2. At 0920 hrs. an aircraft passes over START POINT steering with T.A.S. 148 k. If at 1010 hrs. the navigator pinpoints CROYDON, what is the W/V ?

3. The Co. is 305° C, var. 10° W., dev. as per curve. T.A.S. 220 m.p.h. Drift is 9° P and G/S is 232 m.p.h. Find W/V.

4. T.A.S. 175 k. G/S 175 k. Drift 9° S. Find W/S.

5. Copy and complete :

T.A.S. (k.)	150	180		160
Co. (C)	247°			
Co. (M)				
Co. (T)				305°
Dev. .	5° E.	2° E.	4° W.	3° W.
Var. .	10° E.	16° W.	8° W.	15° E.
G/S .	142		145	
Drift .				
Tr. (T)	265°	155°	092°	
W/S .		25	30	22
W/D .		065°	185°	062°

6. At 0750 hrs. an aircraft passes over BODMIN on Co. 090° T at T.A.S. 150 k. At 0802 hrs. Co. is altered to 024° T. Find the Air Posn. at 0812 hrs., and, if EXETER is pinpointed at 0812 hrs., find the W/V.

7. At 1308 hrs. an aircraft passes over HESTON, steering 320° T at T.A.S. 120 k. At 1318 hrs. alter course to 260° T. If OXFORD is pinpointed at 1328 hrs., find the W/V.

8. On Co. 245° T drift is observed to be 10° P. On Co. 335° T drift is 8° P. Find the W/V if the T.A.S. is 185 m.p.h.

9. Given T.A.S. 170 k., find the W/V from the following :

> Co. 185° T, Drift 7° S.
> Co. 360° T, Drift 10° P.
> Co. 338° T, Drift 11° P.

10. Co. 090° T, T.A.S. 165 k., drift 6° S.　Alter course 60° to port.　Drift 8° S is then observed.　After 10 min. flying on the second course, course is altered 120° to starboard, and the drift is then found to be 5° P.　Find the W/V.

11. Co. 035° M, T.A.S. 130 k., drift 11° P.　On altering course to 156° M, the aircraft flies over an object of which a back bearing is taken and found to be 346° M.　Var. 14° E. Find the W/V.

1. Define :　Dead Reckoning Position ;　Air Position ; Fix ;　Position Line.

2. Using the reference letters given in Exercise VI C (p. 82) express each of the following positions by the lettered co-ordinates method :　(a) HARTLAND PT., (b) 240° HARTLAND 36′.　(A)

3. From MWRE 1520 an aircraft sets Co. at 1040 hrs. for SCARWEATHER LT.　T.A.S. 135 k.　W/V 195°/28 k.　Express the D.R. posns. at 1100 hrs. and 1120 hrs. by bearing and distance from SCARWEATHER.　(A)

4. At 1635 hrs. an aircraft passes over MWDY 0839 on Co. 285° T at T.A.S. 150 k. and at 1650 hrs. a/c 270° T.　At 1735 hrs. the aircraft passes over BRUGES.　Find the mean W/V between 1635 hrs. and 1735 hrs.　(M)

5. From 098° FLAMBOROUGH 25′ Co. is set for DOVER at 1125 hrs., T.A.S. 140 k.　W/V 255°/27 k.　Express the D.R. posn. at 1210 hrs. by lettered co-ordinates.　(M)

6. EDDYSTONE bore 314° C.　Var. 12° W.　Dev. 4° E. EDDYSTONE is 8 n.m. from the aircraft.　State the position of the aircraft as bearing and distance from EDDYSTONE.

F

1. At 1100 hrs. you leave BERRY HEAD steering 058° T at T.A.S. 130 k. W/V 180°/27 k. Find (a) Air posn. at 1130 hrs., (b) Tr., (c) G/S, (d) D.R. posn. at 1130 hrs. (AM)

2. At 0810 hrs. you leave DORTMUND steering 285° T at T.A.S. 150 k. At 0938 hrs. pinpoint ORFORDNESS. Find (a) Air posn. at 0938 hrs., (b) W/V.   (M)

3. At 0735 hrs. you are at HESTON and ordered to s/c BREST. T.A.S. 190 m.p.h. W/V 355°/25 m.p.h. Find (a) Compass co. to steer, (b) G/S, (c) distance, (d) E.T.A., (e) D.R. posn. at 0820 hrs.   (A)

4. 1605 hrs. BARNSTAPLE. Steering 192° M. T.A.S. 225 k.
     1620 hrs. EDDYSTONE. Find W/V.

5. 1300 hrs. LEICESTER. Steering 105° T. T.A.S. 240 m.p.h.
     1330 hrs. SOUTHWOLD LT. Find W/V.   (M)

6. 1750 hrs. C. DE LA HAGUE. Steering 046° M. T.A.S. 200 m.p.h.
     1812 hrs. ST. CATHERINES. Find W/V.   (AM)

7. 1200 hrs. STOKE-ON-TRENT. Co. 215° C. T.A.S. 175 k. W/V 160°/25 k. Find (a) Tr., (b) G/S, (c) D.R. posn. 1240 hrs.   (M)

8. 1038 hrs. BEACHY HEAD. Co. 287° C. T.A.S. 195 m.p.h. W/V 185°/30 m.p.h. Find (a) Tr., (b) G/S, (c) D.R. posn. 1052 hrs.   (AM)

9. 1115 hrs. OKEHAMPTON. Co. 098° C. T.A.S. 165. k. W/V 005°/18 k. Find (a) Tr., (b) G/S, (c) D.R. posn. 1205 hrs.
                                                     (A)

10. 0830 hrs. HESTON. S/c ROUEN. T.A.S. 150 k. W/V 270°/19 k. Find (a) Compass co. to steer, (b) G/S., (c) distance, (d) E.T.A.

0850 hrs. EASTBOURNE. Find (e) T.M.G., (f) G/S, (g) W/V. S/c ROUEN with new W/V.

Find (*h*) Co. C, (*i*) G/S, (*j*) distance, (*k*) E.T.A.   (M)

11. 1420 hrs. BODMIN. S/c NEEDLES. T.A.S. 140 k. W/V 000°/30 k. Find (*a*) Co. C, (*b*) G/S, (*c*) distance, (*d*) E.T.A.

1500 hrs. BILL OF PORTLAND. Find (*e*) T.M.G., (*f*) G/S, (*g*) W/V. S/c BRIDGEWATER with new W/V. Find (*h*) Co. C, (*i*) G/S, (*j*) distance, (*k*) E.T.A.   (A)

12. 2030 hrs. WILHELMSHAVEN. S/c CAMBRIDGE. T.A.S. 180 k. W/V 195°/27 k. Find (*a*) Co. C., (*b*) G/S, (*c*) E.T.A.

2200 hrs. ORFORDNESS bore 234° C. Dev. 5° E.

LOWESTOFT LT. bore 294° C. Dev. 5° E.

Find (*d*) Fix, (*e*) W/V.   (M)

13. 0645 hrs. HESTON. S/c DORCHESTER. T.A.S. 140 k. W/V 270°/20 k. Find (*a*) Co. C, (*b*) G/S, (*c*) D.R. posn. 0720 hrs.

0720 hrs. A/c 206° C. W/V as before.

Find (*d*) Tr., (*e*) G/S, (*f*) D.R. posn. 0730 hrs.

0730 hrs. ANVIL PT. bore 083° C. Dev. 3° E.

Find (*g*) True bearing of ANVIL PT.

0740 hrs. S/c BODMIN. T.A.S. as before. W/V 282°/25 k.

Find (*h*) Co. C., (*i*) G/S.

0805 hrs. START PT. bore 188° C. Dev. 3° E.

Find (*j*) Fix at 0805 hrs.

G

1. An aircraft carrier is steaming 270° T at 30 k. An aircraft is 50 n.m. on bearing 180° T from the carrier, making good a Tr. 315° T at G/S 120 k. Find (*a*) the velocity of the aircraft relative to the carrier, (*b*) the course the aircraft must steer, with no wind, to join the carrier.

2. Aircraft A is making good a Tr. 295° T at G/S 170 m.p.h. Aircraft B is making good a track 027° T at G/S 160 k. At 1200 hrs. A is 40 n.m. on bearing 090° from B. At what time will the aircraft approach nearest to one another and how far will they then be apart ?

3. An aircraft carrier is steaming 220° T at 28 k. What true Co. must an aircraft steer at T.A.S. 145 k. to open on a constant bearing Green 45° if W/V is 085°/15 k. ?

4. Co. of carrier 238° T. Speed 25 k. Aircraft is to patrol on Red 30° at T.A.S. 155 k. W/V 105°/20 k. Find (a) Co. T out, (b) Co. T home.

5. An aircraft based at A is ordered to patrol on bearing 155° T. T.A.S. 160 k. W/V 275°/30 k. The aircraft is to return to base in three hrs. Find (a) Co. T out, (b) T.T.T., (c) Co. T home.

6. What is the radius of action for a 5-hr. patrol on bearing 115° T., at T.A.S. 155 m.p.h. with W/V 195°/25 m.p.h. ?

7. Aircraft B is 65 n.m. on bearing 260° T from aircraft A. A is steering 290° C at T.A.S. 135 k. W/V 180°/20 k. Var. 8° W. Dev. 2° W. Find (a) the two courses (T) which B could steer at T.A.S. 110 k. in order to intercept A, (b) the time taken to intercept on each of these courses, (c) the least T.A.S. at which B could intercept A, (d) the time to intercept at that T.A.S., (e) the true Co. to intercept A when B's T.A.S. is 160 k., (f) the time taken to intercept on that Co.

8. An aircraft is to fly from Base A to Base B which is 210 n.m. on bearing 148° T from A. T.A.S. 155 k. W/V 238°/15 k. Find the distance of the critical point from A.

9. At 1530 hrs. an aircraft carrier is in posn. 54° 45′ N., 0° 38′ E., steaming 155° T at 28 k.

0635 hrs. Aircraft ordered to patrol on Red 50° at T.A.S. 145 k. W/V 270°/22 k.

0705 hrs. Carrier a/c 145° T. Aircraft ordered to rejoin carrier. Find time of rejoining and the position of the carrier at that time. (M)

10. At 1330 hrs. a seaplane is patrolling about a position 40 n.m. on bearing 085° T from a carrier which is at 53° 30′ N., 1° 30′ E. The carrier is steering 108° T at 30 k. in slack water.

The aircraft is ordered to take station 15 n.m. on bearing Green 90°. T.A.S. 132 k. W/V 000°/19 k. Find the true Co. to be steered by the aircraft and the time at which the new position will be reached.   (M)

H

1. At aerodrome A ground pressure is 995 mb. Height of A above mean sea level is 200 ft., and the altimeter is set to read 200 ft. Aerodrome B is 330 ft. above mean sea level and mean sea-level pressure at B is 997 mb. What will the altimeter read on landing at B ?

2. Before leaving aerodrome A, which is 150 ft. above mean sea level, and at which the ground pressure is 1004 mb., the altimeter is set to 150 ft. At aerodrome B, 60 ft. above mean sea level, the ground pressure is 995 mb. Half-way between A and B is a range of hills 2250 ft. above mean sea level. If the aircraft flies from A to B keeping at a height of 2500 ft. by altimeter, what clearance will there be when it passes over the hills ?

3. The I.A.S. is 250 k. Posn. and Instr. Error −4 k. Height 3000 ft. Find the T.A.S.

4. If T.A.S. is 182 m.p.h., height 5500 ft., posn. and instr. error +3 m.p.h., what will be the I.A.S. ?

5. The altimeter is set to 210 ft. at an aerodrome, X, where the ground pressure is 998 mb. When over Y, where the mean sea-level pressure is 1002 mb., the altimeter reads 3000 ft. and the air-speed indicator reads 185 m.p.h. Posn. and Instr. Error +5 m.p.h. Find the T.A.S.

6. At aerodrome X, 280 ft. above mean sea level a sensitive altimeter is set to ground pressure 996 mb. When over Y, 400 ft. above mean sea level, where the ground pressure is 1003 mb., the altimeter reads 2300 ft. Find the true height.

ANSWERS

Exercise I, page 22

(3) 52° 58′ N., 0° 01′ W. ; 52° 00′ N., 0° 59′ W. ; 53° 33′ N., 9° 59′ E. ;
    32° 06′ N., 20° 20′ E. ; 41° 06′ N., 74° 00′ W. ; 33° 52′ S.,
    151° 11′ E.
    (*a*) 59° 53′ ; (*b*) 24° 41′ ; (*c*) 91° 01′.
    (*a*) 16° 08′ ; (*b*) 23° 46′ ; (*c*) 8° 27′.
    (*a*) 84° 05′ 41″ ; (*b*) 68° 59′ 06″.
    (*a*) 15° 07′ 13″ ; (*b*) 2° 56′ 10″.
(8) 226 n.m.   (9) 150 st. m.   (10) 53 n.m., 61 st. m.
(11) Ch. Lat. : 5° 55′ N., 13° 11′ S., 11° 01′ S., 2° 42′ N., 17° 35′ N.,
    9° 57′ S., 25° 12′ S., 3° 34′ N.
    Ch. Long. : 12° 09′ W., 2° 18′ W., 17° 36′ W., 4° 06′ E., 2° 14′ W.,
    21° 23′ E., 37° 47′ W., 4° 04′ W.

Exercise II A, page 27

(2) 000°, 045°, 090°, 135°, 180°, 225°, 270°, 315°.
(3) (*a*) 40° ; (*b*) 50°.   (4) 322°, 144°.   (5) 222°

Exercise II B, page 31

(1) (*b*) 062°.   (2) (*b*) 225°.
(5) Answers for each column left to right :
    312°, 224°, 144°, 303°, 051°, 148°, 313°, 248°
(6) Left to right : 011°, 357°, 358°, 004°.
(7) Left to right : 16° E., 9° W., 15° E., 14° W.

Exercise II C, page 38

Answers left to right, questions 2, 3, 4 :
(2) 054°, 171°, 310°, 145°.
(3) 251°, 173°, 277°, 260°.
(4) 212°, 037°, 318°, 158°.
(5) 11½° W., 10½° W., 11½° W.
(6) 10° W., 11½° W., 9½° W.
(7) 135° T.

Exercise III, page 47

(7) 1.253440.   (8) 3·95.   (9) 7·89.

Exercise IV A, page 53

(2) 1.910000 approx.
(3) 49° 58′ N., 5° 12′ W. ; 51° 02′ N., 4° 32′ W. ; 50° 44′ N., 4° 00′ W. ;
48° 19′ N., 0° 39′ W. ; 48° 34′ N., 3° 49′ W.
(5) 53° 47′ N., 1° 47′ W. ; 50° 43′ N., 3° 33′ W. ; 50° 44′ N., 0° 14′ E. ;
51° 27′ N., 7° 00′ E. ; 52° 06′ N., 5° 07′ E.
(7) (a) 49 ; (b) 51 ; (c) 98 ; (d) 207.
(8) (a) 59 ; (b) 123 ; (c) 183 ; (d) 245.
(9) (a) 60 ; (b) 110 ; (c) 237.

Exercise IV B, page 55

(1) (a) 039° (b) 118° ; (c) 253° ; (d) 339°.
(2) (a) 059° ; (b) 124° ; (c) 224° ; (d) 302°.
(3) 51° 01′ N., 0° 57′ W.   (4) 51° 42′ N., 4° 27′ E.
(5) 50° 49′ N., 3° 03′ W.

Exercise IV C, page 59

(3) (a) 3° 05′ S., 4° 05′ W. ; (b) 1° 22′ N., 4° 04′ W. ; (c) 1° 26′ S.,
5° 40′ W.
(4) (a) 1° 45′ N., 2° 41′ W. ; (b) 2° 14′ S., 4° 26′ E. ; (c) 2° 49′ N.,
8° 01′ E.
(5) (a) 158° ; (b) 127° ; (c) 308°.   (7) 15·8.

Exercise V A, page 63

(1) (a) 075° T, 102 m.p.h. ; (b) 140° T, 203 m.p.h. ; (c) 233° T, 153 k. ;
(d) 305° T, 126 k.
(2) 243° T ; 165 k. ; 50° 11′ N., 4° 53′ W.
(3) 140° T ; 189 k. ; 50° 11′ N., 4° 57′ E.
(4) 107 k.   (5) 206 m.p.h.

Exercise V B, page 66

(1) (a) 30 k., 010° ; (b) 41 m.p.h., 105° ; (c) 22 k., 020° ; (d) 18 k., 242°.
(2) 130 k., 253° T, 172°/22 k.
(3) 159 k., 249° T., 134°/25 k.
(4) 134° T, 140° T, 180 k., 7° S., 012°/21 k.

Exercise V C, page 68

(1) (*a*) 071° T, 136 k. ; (*b*) 315° T, 163 m.p.h. ; (*c*) 213° T, 117 k. ;
    (*d*) 166° T, 164 m.p.h.
(2) (*a*) 149° T, 9° S., 162 k., 1 hr. 28 min. ;
    (*b*) 306° T, 11° P, 121 k., 56 min.
(3) (*a*) 336° C, 1 hr. 11 min. ; (*b*) 075° C, 1 hr. 34 min. ;
    (*c*) 137° C, 1 hr. 8 min.
(4) (*a*) 123° C, 1 hr. 1 min. ; (*b*) 090° C, 1 hr. 22 min.
(5) 231° C, 177 k., 1207 hrs.

Exercise V D, page 72

(1) 150°/28 k.   (2) 187°/12 k.
(3) 130°/48 m.p.h.   (4) 039°/37 m.p.h.

Exercise VI A, page 76

(1) 118° T.   (2) 50° 14′ N., 3° 22′ W.
(3) 50° 18′ N., 0° 37′ E.   (4) 50° 43′ N., 1° 46′ W.
(5) 50° 22′ N., 2° 16′ W. ; 056° T. ; 97 n.m. ; 166 k. ; 0910 hrs.
(6) 077° T, 120° T, 092° T, 092° T.

Exercise VI B, page 79

(1) 50° 24′ N., 2° 07′ W.   (2) 50° 31′ N., 5° 06′ W.
(3) 50° 24′ N., 2° 25′ W.
(4) 52° 22′ N., 1° 51′ E. ; 235° C ; 190 k. ; 98 n.m. ; 1311 hrs.

Exercise VI C, page 82

(1) (*a*) PHHD 1228 ; (*b*) BXLG 1144 ; (*c*) BXEA 3132.
(2) (*a*) 057° PHHD 21 n.m. ; (*b*) 068° BXLG 30 n.m. ;
    (*c*) 034° BXEA 37 n.m.
(3) (*a*) 51° 15′ N., 2° 08′ E. ; (*b*) 50° 40′ N., 1° 22′ E. ;
    (*c*) 54° 10′ N., 0° 12′ E. ; (*d*) 49° 36′ N., 2° 14′ W.
(4) (i) (*a*) MWDK 1508, (*b*) BXBD 4022, (*c*) CMAB 1012,
    (*d*) PHEA 3646 ;
    (ii) (*a*) 018° MWDK 16 n.m., (*b*) 019° BXBD 42 n.m.,
    (*c*) 035° CMAB 14 st. m., (*d*) 040° PHEA 54 st. m.
(5) 067° T.
(6) (*a*) BKDK 0000 ; (*b*) BKBD 2348 ; (*c*) BKML 2312 ;
    (*d*) ACBD 3748 ; (*e*) ACML 3712 ; (*f*) NOBD 5400 ;
    (*g*) ACAB 1400.

Exercise VII A, page 89

(*Note*: In plotting questions, answers to parts are given in the order in which the parts occur in the questions.)

(1) (*a*) 235° C; (*b*) 154 k.; (*c*) 146 n.m.; (*d*) 1457 hrs.; (*e*) 50° 42′ N., 1° 01′ W.
(2) 012° C; 155 m.p.h.; 234 st. m.; 1101 hrs.; 49° 49′ N., 2° 08′ W.
(3) 109° T, 121° M, 125° C; 161 k.; 150 n.m.; 1226 hrs.; 51° 08′ N., 2° 52′ W.
(4) 228° C; 183 k.; 188 n.m.; 1117 hrs.; 52° 25′ N., 1° 31′ W.
(5) 097° C; 177 m.p.h.; 353 st. m.; 2315 hrs.; 51° 42′ N., 0′ 07′ E.
(6) 204° T, 214° M, 211° C; 169 k.; 151 n.m.; 0909 hrs.; 52° 06′ N., 0° 12′ W.

Exercise VII B, page 90

(1 243ᶜ T; 138 k.   298°/20 k.
(2 033ᶜ T; 146 k.   078°/25 k.
(3 296° T; 170 k.   092°/23 k.
(4 276° T; 142 k.   250°/26 k.
(5 054° T; 190 k.   49° 18′ N., 1° 08′ W.
(6) 122° T; 195 k.   51° 22′ N., 4° 40′ E.

Exercise VII C, page 91

(1) 096° T, 104° M, 108° C; 175 k.; 252 n.m.; 2141 hrs.; 100° T 173 k.; 333°/14 k.; 101° T, 109° M, 113° C; 174 k.; 183 n.m. 2143 hrs.; 51° 23° N., 5° 41′ E.
(2) 224° T, 235° M, 231° C; 159 k.; 220 n.m.; 1353 hrs.; 216° T 126 k.; 258°/32 k.
(3) 289° T, 300° M, 296° C; 182 m.p.h.; 221 st. m.; 1953 hrs. 292° T; 164 m.p.h.; 262°/18 m.p.h.; 294° T, 305° M, 301° C 165 m.p.h.; 142 st. m.; 2002 hrs.; 49° 33′ N., 3° 20′ W.
(4) 125° T, 134° M, 138° C; 215 m.p.h.; 354 st. m.; 1709 hrs. 119° T; 200 m.p.h.; 214°/28 m.p.h.; 133° T, 141° M, 144° C 198 m.p.h.; 204 st. m.; 1717 hrs.; 51° 41′ N., 3° 12′ E.
(5) 349° T, 360° M, 002° C; 178 k.; 210 n.m.; 1736 hrs.; 340° T 157 k.; 043°/34 k.; 355° T, 006° M, 008° C; 153 k.; 143 n.m. 1747 hrs.; 50° 47′ N., 2° 53′ W.

Exercise VII D, page 92

(1) 208° T; 155 k.; 286°/33 k.; 230° T, 241° M, 237° C; 149 k.; 167 n.m.; 2001 hrs.; 49° 43′ N., 2° 48′ W.
(2) 188° T, 199° M, 197° C; 159 k.; 204 n.m.; 1147 hrs.; 50° 31′ N., 1° 32′ W.; 188° T; 148 k.; 188°/2 k.; 188° T, 199° M, 197° C; 148 k.; 144 n.m.; 1158 hrs.; 49° 05′ N., 1° 37′ W.

(3) 280° T ; 151 k. ; 221°/34 k. ; 341° T, 352° M, 352° C ; 189 k. ;
    56 n.m. ; 1625 hrs. ; 51° 23′ N., 2° 36′ W.

(4) 334° T, 344° M, 344° C ; 195 k. ; 161 n.m. ; 1921 hrs. ; 50° 34′ N.,
    1° 49′ W. ; 325° T ; 183 k. ; 065°/27 k. ; 047° T, 057° M, 062° C ;
    155 k. ; 77 n.m. ; 1935 hrs. ; 51° 01′ N., 1° 07′ W.

Exercise VII E, page 94

1) 12° 42′ N., 14° 29′ W.   (2) (a) 779 ; (b) 649.
3) (a) 897 ; (b) 747.

	Tr.	Dr.	Co. (T)	Var.	Co. (M)	Dev.	Co. (C)
6)	—	—	099°		111°	—	108°
	300°	—	310°		299°	—	—
	—	10° S.	—	14° E.	—	3° E.	—

Exercise VIII, page 111

(1) 350° T ; 1127 hrs.
(2) 118° T ; 82½ n.m. ; 303° T ; 1514 hrs.
(3) 159° T ; 1032 hrs. ; 49° 00′ N., 4° 17′ W.
(4) 49° 54′ N., 4° 18′ W. ; 159° T ; 49° 55′ N., 4° 42′ W.; 49° 15′ N.,
    4° 12′ W. ; 330° T ; 1313 hrs. ; 49° 52′ N., 4° 51′ W.
(5) 283° T ; 246° T ; 255° T ; 50° 14′ N., 2° 10′ W. ; 49° 26′ N.,
    3° 23′ W. ; 022° T ; 1308 hrs. ; 50° 08′ N., 4° 44′ W.
(6) 096° T ; 53° 44′ N., 4° 52′ E. ; 224° T ; 52° 14′ N., 2° 24′ E. ;
    52° 09′ N., 2° 21′ E. ; 50° 33′ N., 0° 07′ W. ; 058° T ; 1145 hrs. ;
    51° 43′ N., 2° 02′ E.
(7) (i) 114° T, 147 k. ; (ii) 078° T, 150 k. ; (iii) 93 k., 007° T ; (iv) 17
    n.m. ; (v) 1510 hrs. ; (vi) 059° T, 1503 hrs. ; (vii) 106° T, 1600 hrs.
    i) 073° T, 027° T ; (ii) 115 k.
    i) 245° T ; (ii) 1 hr. 55 min. ; (iii) 045° T.
(10 491 st. m.
(11) (i) 204° T ; (ii) 1 hr. 57 min. ; (iii) 036° T.
(12) (i) 111° T ; (ii) 1413 hrs. ; 53° 11′ N., 8° 19′ E. ; (iii) 250° T ;
    (iv) 52° 28′ N., 2° 25′ E.
(13) 73·4 n.m. ; 72·3 n.m.

Exercise IX B, page 132

(1) 270 ft.   (2) 90 ft.   (3) 610 ft.
(5) 5760 ft. ; 8576 ft. ; 9280 ft. ; 7276 ft.
    1013·9 mb.

Exercise IX C, page 136

1) 107 m.p.h.   (2) 136 k.
3) 189 k. ; 275 k. ; 228 m.p.h. ; 253 m.p.h. ; 296 k.
4) 284 m.p.h. ; 308 m.p.h. ; 154 k. ; 206 k.
5) 197 m.p.h.

Miscellaneous Examples

A, *page 161*

(1) (*a*) 53 n.m. ; (*b*) 61 st. m.
(2) (*a*) 21,600 n.m. ; (*b*) 24,873 st. m.
(3) 3° 05′ S., 1° 18′ W.   (4) 4° 20′ S., 11° 30′ E.
(5) 38° 49′ N., 11° 54′ W.

B, *page 161*

(2) Dr. 3° S., 4° P ; Tr. 198°, 180° ; Co. 253°, 121°.
(5) Columns from left to right :
    031° C, 8° W. ; 223° T, 4° W. ; 323° T, 329° C ; 010° T, 358° M ;
    12° W. ; 3° E. ; 265° M, 6° E. ; 351° M, 13° E.
    Obs. 4° E., Pilot 2° W.
(7) Obs. 3° W., Pilot 4° W.
(8) Columns left to right :
    193° T, 205° M, 202° C ; 326° T, 318° T, 312° C ; 6° P, 9° W.,
    3° W. ; 030° T, 040° M, 045° C.
(9) 030° T.
(10) Tr. 315° ; G/S 178 m.p.h., Co. 325° T ; T.A.S. 160 m.p.h. W/V
    264°/34 m.p.h.

C, *page 162*

(3) 1·58.   (5) 138° T.

D, *page 163*

  318°/21 k.   (2) 274°/32 k.   (3) 043°/39 m.p.h.   (4) 28 k.
  1st column : Co. (M) 252°, Co. (T) 262°, Dr. 3° S., W/S 12 k.,
    W/D 039°.
  2nd column : Co. (C) 161°, Co. (M) 163°, Co. (T) 147°, G/S 178 k.,
    Dr. 8° S.
  3rd column : T.A.S. 147 k., Co. (C) 116°, Co. (M) 112°, Co. (T)
    104°, Dr. 12° P.
  4th column : Co. (C) 293°, Co. (M) 290°, G/S 172 k., Dr. 7° P,
    Tr. (T) 298°.
  50° 51′ N., 3° 40′ W. ; 329°/25 k.   (7) 183°/14 k.
  288°/41 m.p.h.   (9) 036°/41 k.   (10) 289°/46 k.
  118°/25 k.

E, *page 164*

(*a*) MWLQ 0128 ; (*b*) BXRE 4238.
260° SCARWEATHER 18′ ; 080° SCARWEATHER 30′.
284°/23 k.   (5) BVBD 2302.
126° EDDYSTONE 8′.

F, *page 165*

(1) (*a*) 50° 59′ N., 2° 02′ W. ; (*b*) 049° T ; (*c*) 146 k. ; (*d*) 51° 12′ N., 2° 02′ W.
(2) (*a*) 59° 29′ N., 1° 45′ E. ; (*b*) 015°/17 k.
(3) (*a*) 233° C ; (*b*) 207 m.p.h. ; (*c*) 280 st. m. ; (*d*) 0856 hrs. ; (*e*) 49° 45′ N., 2° 43′ W.
(4) 100°/32 k.   (5) 196°/26 m.p.h.   (6) 088°/33 m.p.h.
(7) (*a*) 214° T ; (*b*) 159 k. ; (*c*) 51° 33′ N., 3° 48′ W.
(8) (*a*) 290° T ; (*b*) 201 m.p.h. ; (*c*) 50° 58′ N., 0° 49′ W
(9) (*a*) 088° T ; (*b*) 162 k. ; (*c*) 50° 48′ N., 0° 28′ W.
(10) (*a*) 172° C. ; (*b*) 157 k. ; (*c*) 137 n.m. ; (*d*) 0922 hrs. ; (*e*) 149° T (*f*) 150 k. ; (*g*) 245°/34 k. ; (*h*) 179° C ; (*i*) 145 k. ; (*j*) 86 n.m. (*k*) 0926 hrs.
(11) (*a*) 088° C ; (*b*) 134 k. ; (*c*) 121 n. m. ; (*d*) 1514 hrs. ; (*e*) 088° T (*f*) 130 k. ; (*g*) 004°/39 k. ; (*h*) 351° C ; (*i*) 105 k. ; (*j*) 42 n.m. (*k*) 1524 hrs.
(12) (*a*) 250° C ; (*b*) 166 k. ; (*c*) 2218 hrs. ; (*d*) 52° 24′ N., 2° 10′ E. (*e*) 224°/33 k.
(13) (*a*) 249° C ; (*b*) 122 k. ; (*c*) 50° 52′ N., 2° 01′ W. ; (*d*) 190 T (*e*) 135 k. ; (*f*) 50° 30′ N., 2° 08′ W. ; (*g*) 075° T ; (*h*) 287° C (*i*) 120 k. ; (*j*) 50° 18′ N., 3° 39′ W.

G, *page 166*

(1) (*a*) 100 k., 328° ; (*b*) 346° T.
(2) 1210 hrs., 12 n.m.   (3) 256° T.
(4) (*a*) 234° T ; (*b*) 064° T.
(5) (*a*) 164° T ; (*b*) 1 hr. 21 min. ; (*c*) 325° T.
(6) 384½ st. m.
(7) (*a*) 092° T, 247° T ; (*b*) 16 min., 2 hr. 36 min. ; (*c*) 23 k. ; (*d*) 29 min. ; (*e*) 088° T ; (*f*) 13½ min.
(8) 105 n.m.   (9) 0739 hrs. ; 53° 52′ N., 1° 22′ E.
(10) 248° T, 1348 hrs.

H, *page 168*

(1) 470 ft.   (2) 220 ft.   (3) 259 k.
(4) 199 m.p.h.   (5) 2210 ft.   (6) 2900 ft.